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# STORAGE BATTERY ENGINEERING

A PRACTICAL TREATISE FOR ENGINEERS

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BY

LAMAR LYNDON, B.E., M.E.

*Consulting Electrical Engineer*

*Assoc. Member American Inst. Electrical Engineers*

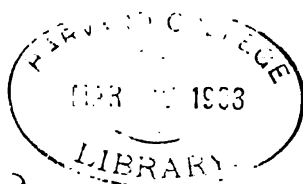
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## PREFACE.

The evident and long unfulfilled need of a practical work on the storage battery, particularly adapted for electrical engineers who are not chemists, and on the details of its engineering applications, together with the pleasant reception accorded some writings of the Author on this line, in the *Electrical World and Engineer*, last year, have induced the preparation of this book.

It is intended to assist the practicing engineer in designing, installing and maintaining battery equipments, and to guide him in the selection of types of batteries and auxiliary apparatus best suited to the service which they are to perform, and at the same time impress upon the technical public, both the advantages and limitations of the storage battery in practice.

Mathematics have been avoided as far as possible, and when the proper treatment of any subject has compelled their use, all operations have been carried through with explanatory text, so that the reasoning may be easily followed, and in many instances each mathematical discussion is further elucidated by a concrete example.

The works and papers consulted are given in detail in the Bibliography which follows, and all useful information therein contained and within the scope of this work has been freely used, as have also a few cuts and diagrams.

The Osmotic and Thermodynamic theories of the Storage Battery have not been discussed, as their comprehension requires more electro-chemical knowledge than the majority of electrical engineers possess, and this work is essentially a practical engineers' manual.

The Author desires to acknowledge the kind assistance and encouragement from many sources, in the production of this book. Among these should be mentioned Dr. Samuel

Sheldon, Prof. A. S. Chessin, A. S. Hubbard, W. W. Donaldson, Woolsey McA. Johnson, H. B. Moses, and my brother, Edward Lyndon. The National and the Gould Storage Battery Companies have also been most courteous in supplying information, drawings and diagrams, the use of which have added no little to the practical value of the book.

LAMAR LYNDON.

NEW YORK, December, 1902.

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# **PART I**

## **THE LEAD STORAGE BATTERY**





## CHAPTER I.

### GENERAL THEORY OF THE STORAGE BATTERY.

---

Any voltaic couple which is reversible, *i. e.*, capable of regeneration after exhaustion by passing an electric current through it in a direction opposite to that of flow on discharge, is a storage battery or accumulator.

There are many couples which fulfill this condition and can be used as storage batteries, but with the exception of lead peroxide against lead, and lead peroxide against zinc, none, so far, has proven commercially available for engineering purposes. Edison has, within the past year, produced an iron-nickel cell which promises to be of value in electric motor car propulsion, but for reasons elsewhere given in this work, it can never compete with the lead-lead or the lead-zinc battery, for power station service.

The lead-lead cell being in general use—practically to the exclusion of all other types—it, only, will be considered in detail here. The engineering applications and methods of installation will be of the same character with any type of battery used, the only differences being in voltages, and the number of cells required for any given equipment.

The lead-lead battery consists of two elements—the positive and negative—and the electrolyte. The elements are sponge lead (Pb) for the negative, and peroxide of lead ( $\text{PbO}_2$ ) for the positive elements, these forming the active couple. They are immersed in the electrolyte which is dilute sulphuric acid. The positive and negative plates can readily be distinguished by their colors. The peroxide plate is of a velvety brown chocolate color and the lead sponge is a light gray. The hardness is also an indication, the positive coating being usually hard like soapstone, while the negative coating is soft and can be cut into with the thumb nail.

Sponge lead is not ordinary metallic lead, but is some allotropic form of this metal. Its conversion into metallic lead is accompanied with the production of heat.

Darrieus has shown that the E.M.F. between soft, metallic lead and lead peroxide immersed in dilute sulphuric acid of about 1.225 sp. gr. is 1.46 volts, while under the same conditions of temperature, acid concentration and disposition of plates the E.M.F. between electrolytically formed lead sponge and peroxide is 1.94 volts.

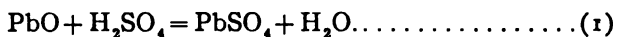
The explanation which was at one time given to make clear the action of the storage battery is as follows:

When the battery discharges, the electric current passing through it decomposes the water in the electrolyte, liberating hydrogen and oxygen, the first being evolved at the positive or peroxide element, and the oxygen at the negative or sponge lead plate. The oxygen and hydrogen, at the instant of liberation, are chemically more active than in their fixed or ordinary state, and combine more readily with other substances. The nascent hydrogen combines with certain molecules of oxygen in the lead peroxide, forming water, and the abstraction of these molecules of oxygen reduces the degree of oxydization of the peroxide, and changes it into lead oxide ( $\text{PbO}$ ). The oxygen liberated at the negative pole combines with the negative or lead plate to form lead oxide ( $\text{PbO}$ ). Therefore complete discharge would change the positive and negative elements into the same compound, the voltaic couple would no longer exist, and no further discharge could be obtained from the battery.

If, however, a charging or regenerating current be sent through the battery in a direction opposite to that in which current flowed on discharge, the gases of decomposition are liberated also oppositely, the oxygen being formed at the positive and the hydrogen at the negative plates. The oxygen at the positive pole combines with the lead oxide, adding a molecule of oxygen and changing the element to lead peroxide, while the hydrogen combines with the molecule of oxygen in the negative element to form water, and thus abstracts the oxygen from the negative plate, turning it back to lead. The battery is, then, when fully changed or

charged, exactly in the same state as before, and becomes again an active, voltaic couple.

A most important chemical combination which takes place on discharge, is that of sulphatation, which is the change of lead oxide ( $\text{PbO}$ ) into lead sulphate ( $\text{PbSO}_4$ ). Lead oxide cannot exist, as such, in the presence of sulphuric acid. The  $\text{SO}_3$  in the acid combines with lead oxide to form lead sulphate. This is expressed by the equation:



It is therefore obvious that as fast as the lead peroxide on the positive and the sponge lead on the negative plates, are changed to lead oxide, the sulphuric acid turns them into lead sulphate. This latter action is quite independent of the electric current, and will take place if lead oxide be simply immersed in sulphuric acid, though neither lead nor lead peroxide is attacked by it.

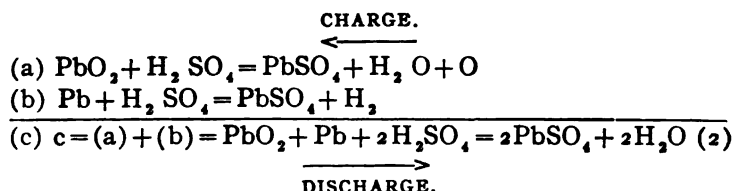
This, while quite a simple and attractive theory, is upset by thermo-dynamical considerations. Lead oxide cannot be chemically changed into lead sulphate, without the liberation of heat, which represents all or a large portion of the stored energy in the battery, and since this energy is returned, it is clearly impossible that the simple chemical combination takes place. The theory which is now generally accepted is that the change from lead peroxide and sponge lead, to lead sulphate, is direct and does not pass through any intermediate stage. The rest of the theory advanced, however, is true.

Lead sulphate is white; possesses a high resistance, in fact, is an insulator, and if a battery should be completely discharged and the elements turned to lead sulphate, it would become worthless, the reduction of pure lead sulphate to  $\text{Pb}$  or  $\text{PbO}_2$  being difficult, if not impossible. Therefore, there is a limit below which a battery should never be discharged and this limit is such that the amount of sulphate formed is comparatively small, enough lead or lead peroxide remaining and being mixed therewith to keep down the resistance, and admit of passage of charging current and

regeneration of the battery. Furthermore, the change from  $\text{PbO}_2$  or  $\text{Pb}$  to  $\text{PbSO}_4$  causes an increase in volume of the active material, and if too much sulphate be allowed to form, there is danger of breaking the grid or forcing off the active material.

Changes also take place in the electrolyte during charge and discharge. On charge, the  $\text{SO}_3$  in combination with the active material and forming the lead sulphate, is given up to the liquid, which therefore gains weight and its density increases. On discharge, the converse action takes place; the  $\text{SO}_3$  is taken up by the lead and lead peroxide to form sulphate, and the density of the liquid decreases.

This rather labored explanation of the changes which take place, is concisely set forth by the reversible chemical equations.



Equation (a) expresses the reactions at the positive plate. (b) those at the negative and (c) the combined effect, is the fundamental equation of the lead storage battery.

The equation of charge shows that both the negative and positive electrodes start as lead sulphate ( $\text{PbSO}_4$ ) and, combining with the dissociated gases of the water in the electrolyte, they turn into lead and lead peroxide, respectively. Also,  $\text{SO}_3$  is released, which, combining with the  $\text{H}_2\text{O}$  in the electrolyte, forms sulphuric acid.

Read from left to right, it is the equation of discharge, and shows the changes of lead and lead peroxide on the negative and positive plates respectively, into lead sulphate and the reduction of sulphuric acid to water.

It is not to be supposed that the reactions, as explained or given by the equation, show all the changes and transformations which occur. There are many other intermediate

reactions, and by-products of decomposition, but these belong more strictly to the chemistry of the storage battery, and are therefore beyond the scope of this text. The reader is referred to the works mentioned in the bibliography for the complete chemical discussions of the storage battery. It may be stated, however, that the chemical theories are widely at variance, and the fact is, the chemistry of the accumulator is, by no means, perfectly understood.

The voltage of a battery depends on the character of the metals or metallic compounds forming the elements, and on the density or concentration of the electrolyte. The voltage of a lead-lead battery is that of sponge lead against lead peroxide as long as any particles of these materials are on their respective plates. Theoretically, if the elements only be considered, and the density of the electrolyte be maintained constant, the E.M.F. of a battery should be constant up to the point of reduction to sulphate of the last traces of lead peroxide and lead, and then suddenly fall to zero. As a matter of fact, the voltage falls gradually from the beginning to end of discharge, and its failure to follow the theoretical law has been the subject of no little speculation and research.

Some investigators—notably Fitz-Gerald, Darrieus, and the late Mr. Griscom—have formulated a theory for the chemical reactions in a lead-lead battery which differs somewhat from the one before given, and which is intended to explain the voltage variations and account for certain products of chemical combination which have been found to occur in storage cells.

This theory is that on passage of current,  $\text{H}_2\text{SO}_4$  breaks up into hydrogen, ( $\text{H}_2$ ) and sulphion ( $\text{SO}_4$ ) at the negative and positive electrodes, respectively. The  $\text{SO}_4$  at the positive plate combines with the  $\text{H}_2$   $\text{SO}_4$  of the electrolyte and forms  $\text{H}_2\text{SO}_4$  and  $\text{H}_2\text{S}_2\text{O}_8$  or persulphuric acid. This latter compound was first observed by Bertholet in 1878 and afterwards investigated by Robertson, besides the other authorities cited.

Persulphuric acid is an unstable compound which begins to decompose as soon as the current which produced it ceases to flow, and also under the influence of heat. It is

supposed to produce the high potential difference of a cell on charge when battery has become fully charged, or at least, it accounts for a large percentage of the increase above the normal potential difference of two volts.

It is also held by some investigators that the lead peroxide, when fully charged, is not the ordinary peroxide,  $\text{PbO}_2$ , but the hydrated peroxide,  $\text{H}_2\text{Pb}_2\text{O}_8$ , or, possibly, a still higher oxide, such as perplumbic acid  $\text{H}_2\text{Pb}_2\text{O}_7$ .

Gladstone and Tribe observed that on charge, the positive plate of a battery absorbs 34 per cent. more of oxygen than does the negative of hydrogen. This results in the releasing of free fixed hydrogen from the negative element some time before oxygen begins to pass off from the positive, as may always be seen when batteries are nearing the end of charge. This could readily be accounted for by the production of higher oxides of lead which would require more oxygen to produce them than does  $\text{PbO}_2$ .

The theory of Gladstone and Tribe, that the excess of oxygen required at the positive plates is due to local action, has no foundation in fact. No cell could last except through very few discharges if such local action did exist.

There are other investigators who do not accept these theories, and the German school of the present day controverts them.

Elbs and Schönherr, in their researches, have found that while persulphuric acid is formed when charge is prolonged in high density electrolyte—1.300 to 1.500 sp. gr.—in acid of density low enough for practical battery work no appreciable quantity is liberated, and in any case, it is not a primary product but an accidental one.

Also  $\text{H}_2\text{S}_2\text{O}_8$  is endothermic—that is, it absorbs energy in formation, and requires therefore a high E.M.F. to produce it—somewhat higher than the normal 2 volts of the lead-lead peroxide couple.

Gladstone and Hibbert have further shown that if persulphuric acid be added to the electrolyte at the anode, no increase of E.M.F. is observable, but on the contrary, there is a slight diminution. These results were later confirmed by Mugdan.

Dolezalek shows that no irreversible chemical actions take place in a battery on charge which would be the case if persulphuric acid were formed; and that the high voltage on charge—up to the point of gassing—and gradually decreasing voltage on discharge, are due to great changes in the density of the electrolyte, which occur within the pores of the plates. (It will presently be seen how differences in electrolyte density affect the voltage.)

These changes are far greater than those which take place in the visible electrolyte surrounding the plates, and without doubt the explanation of Dolezalek is the logical and correct one.

The rate of current flow at which a battery may be discharged depends on the area of the surface on which the electrolyte acts. The active area in any cell is equal to the sum of the areas of the *positive* plates, which area for each positive is = Length x Breadth x 2, the factor 2 being introduced because *both* sides of the plate are active.

The unit of storage battery capacity is the ampere hour—the product of rate of discharge by the time during which this discharge lasts, giving the total capacity, the battery being considered as completely discharged when the minimum voltage of 1.8 is reached. The capacity varies, however, with the rate of discharge, being less at rapid than at slow rates. The eight-hour rate is generally taken as normal, *i. e.*, a fully charged battery having a capacity of 80 ampere hours, will discharge 10 amperes continuously for eight hours, without the voltage falling below 1.8 volts.

It has been shown that  $\text{SO}_2$  is abstracted from the electrolyte on discharge. If all the  $\text{SO}_2$  were taken from the sulphuric acid, water, only, would be left, in which the couple would show an E.M.F. of only about 1.46 volts. The  $\text{SO}_2$  is taken up from the acid only at those points and surfaces where it is in contact with the plates. As the  $\text{SO}_2$  is removed the density decreases and causes circulation, allowing fresh acid to take the place of the exhausted electrolyte. The chemical action is quickest, however, in the minute pores of the plates, where circulation is difficult. This explains the recuperative power of the storage battery, which causes the



voltage to rise after discharge has taken place, if the battery is allowed to stand for a few minutes on open circuit, giving time for the water or highly dilute acid in the pores to diffuse out into the mass of denser acid, and the latter to enter into the pores.

Owing to the fact that the current flows out of the battery on discharge from the peroxide element, it has been customary to call it the positive, and the element at which the current flows into the battery, has been termed the negative. This has arisen from the definition of the positive and negative poles of the dynamo electric machine, as the poles at which current leaves and enters the armature, respectively.

Considered as a voltaic couple, this is decidedly erroneous, as the positive element is that from which current flows, and the negative that to which it flows. Obviously, the direction of current flow in a battery on discharge, is from the so-called negative to the positive. Metallic lead stands high in the list of elements arranged in their order of value as electro positives, while lead peroxide is one of the lowest in the list. Therefore, considered voltaically, the accepted polarities are wrong, but considered as a source of current, or E.M.F., they have been correctly named. As it is in the latter capacity that an engineer views the storage battery, the customary usage will be here adhered to.

The term "charged" does not mean that any electrical energy as such, has been given to the plates or resides in them. It means only that the chemical condition of the elements is such that they form an active voltaic couple or battery, and in their general behavior differ in no wise from an ordinary primary element.

This chemical condition is produced in practice by the action of the electric current, but if sponge lead and lead peroxide, manufactured by some purely chemical means, as they often are, be pasted on to negative and positive grids respectively, a battery will result in which the plates are fully and completely charged.

A charged cell, then, is one in which the positive plates are coated with lead peroxide and the negatives with sponge lead, and a discharged cell is one in which lead sulphate has

formed on the elements. The electricity has no bearing on the question of charge or discharge, further than as a reducing agent in one direction, and as a product of the energy of chemical change, in the other.

Polarization is a phenomenon which occurs on the passage of current between two electrodes immersed in an electrolyte, and its effect is always to oppose the flow of current and to reduce it.

It is customary to consider all effects resulting from electrolytic decomposition which oppose the current producing them, as polarization. There are, however, two different causes which tend to obstruct current flow, namely, increase in ohmic resistance and counter E.M.F. The author prefers to consider the change in ohmic resistance as such only, and confine the meaning of the term "polarization" to the counter E.M.F. effect.

The passage of current through the electrolyte decomposes some or all of the compounds of which it is formed and on breaking up, the elements or other compounds which are released, may be dissolved in the electrolyte; pass off in the form of gas; surround the electrodes as a film; absorbed or occluded in the pores of the electrode, or may enter into chemical combination with the material of the electrodes.

The formation of a film, whether gaseous or of some salt of the material of which the electrodes are made, would increase the resistance. The change in the chemical composition of the electrolyte or electrodes, or the action of the gases surrounding, or occluded by, the electrodes, will set up a counter E.M.F. and the joint action of these two is to oppose the flow of current.

The most important of all polarizing agents liberated, is hydrogen. This being electro-positive, it travels to the negative electrode and sets up an E.M.F. in opposition to the impressed E.M.F.

## CHAPTER II.

### GENERAL REQUIREMENTS.

---

As has been pointed out, the capacity of a storage battery is dependent on the area exposed to the action of the electrolyte. Therefore, the most efficient use of material requires that it be so shaped or fashioned as to give the greatest amount of exposed surface per unit mass of lead.

The electrolytic action cannot penetrate to any appreciable depth into the surface of a solid plate, and consequently that portion of the lead or lead peroxide which is acted on electrolytically, must be in a finely divided or porous state, in order to present a large surface to the electrolyte.

Neither sponge, lead, nor lead peroxide possesses strength, rigidity or high conductivity. Mechanical considerations require the first two, and without the latter, the current could not be efficiently conducted away, even if the chemical constituents of the battery were perfect. Therefore, the battery plate must consist of two parts, *i. e.*, the grid, which is a rigid framework or plate, and the active material which is the finely divided and porous lead or lead peroxide.

The grid gives the necessary solidity and strength to the plate, and also affords the required conducting path to carry current and distribute the electrical—and consequently the chemical—action, evenly over the surface of the elements.

The active material is either formed on the grid by electrolytic or chemical methods, or made up separately and mechanically applied to the grid.

Although the action of the electrolyte cannot penetrate to any appreciable depth on a solid plate, as stated, the

layer of active material may be comparatively thick, if it be porous enough to allow of the penetration of the electrolyte.

The principal requirements to be fulfilled for the production of a satisfactory storage battery plate, are:

1. The arrangement of grid and active material shall be such that the current must flow equally through all portions of the active material. This requires that the resistance shall be the same from any two points on the surface of the element to the terminal lug. This is, of course, an impossible condition theoretically, but it can be sufficiently approached to meet all practical requirements, by proper design of grid and securing firm adherence of active material thereto.

2. The grid should be so constructed that it can expand, changing its volume as that of the active material changes under the action of current and electrolyte. This is also difficult—in fact, with most types, impossible. Inability of designers to meet this requirement causes most of the troubles in storage batteries. The expansion on formation is very great, and the expansion and contraction on discharge and charge are of marked degree.

3. Active material must be fast to the grid and in electrical contact therewith. This can be done when the plates are manufactured, but if the active material expands and the grid does not, and condition No. 2 be not fulfilled, the active material will in time lose both mechanical and electrical contact.

4. The grid should resist the action of the acid. This is also a practically impossible requirement. In certain types of batteries it is in no wise necessary, but in most is desirable. At present, manufacturers have to be content with producing a grid that will last as long as the active portion of the plate.

5. The grid must be of such material that there can be no local action between itself and the active material. There is no difficulty in securing this condition, and in some varieties of batteries the active material is made from the same lead sheet, making local action impossible.

6. Ample provision should be made for circulation of the

electrolyte, so that alterations of concentration may quickly equalize. This is important, especially in batteries which are to be charged and discharged at rapid rates.

7. The active material must expose the greatest possible surface to the electrolyte. This is obtained by methods, of which there are a large number to be given later.

There are two generic types of storage battery plates; one, known as the Planté type, is made by preparing lead plates so that a large area is exposed and then chemically or electro-chemically oxydizing the surface into lead peroxide, which forms the positive plates. To form negatives the peroxide plates are connected as cathodes, and the hydrogen set free on passage of current, reduces the peroxide to metallic sponge lead. By this method of formation a thin layer of active material is produced which is porous and firmly adherent.

The other type is that in which the active material is made up in the form of a paste or powder, and applied to the grid, generally being compacted under heavy pressure. This is known as the Faure type, usually called, in the trade, the "pasted plate." Each method of manufacture has its advantages, and each type of battery finds conditions to which it is best suited. The patents on grids, forms of plates, methods of forming, and on complete processes, are legion. Many of the best processes are secret, and never exposed to the patent office or the technical public.

## CHAPTER III.

### ON VOLTAGE AND ITS VARIATION.

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As indicated in Chapter I, the voltage of a storage battery rises gradually as charge proceeds, until a maximum is reached. When discharge takes place, the voltage sinks gradually until a minimum value is attained. These voltage changes are usually represented by diagrams called voltage curves, which are simply curves drawn on rectangular co-ordinates the abscissæ representing the time, in minutes or hours, and the ordinates, the voltage at the terminals of the cell. By reference to these curves, the voltage, at any period during the time of charge or discharge, may be determined, and by comparison of the charge and discharge curves plotted to the same scale, the efficiency of a cell may be computed.

It is evident, from what has preceded, that the more porous the active material, and the better the circulation of the electrolyte, the less will be the fall in the voltage curve, as discharge proceeds. Figure 1 shows charge and discharge curves of a certain cell. It will be seen that the curve of charge consists of two parts, one at which the voltage stays reasonably constant at between 2.2 and 2.3 volts, and the other part, occurring toward the end of charge, being a continuous rise from about 2.3 to 2.6.

It is probable that intermediate chemical changes begin to take place at the point where the curve begins to rise rapidly, and also that gas is produced and the effects of polarization become more marked.

The discharge curve also shows a like form, except in a reverse direction: the voltage falls quickly to about 2 volts, and then continues at very nearly a constant value until a certain point in the curve is reached toward the end of dis-

charge, when it begins to fall off very rapidly, and if the discharge be continued, would quickly drop to zero. This sudden fall in voltage is due to a number of causes, the most important of which is the formation of sulphate on the surface of the plate preventing access of electrolyte to the inner pores of the active material. The electrolyte, which is enclosed in these pores, rapidly turns to water by reason of the abstraction of the  $\text{SO}_3$  from the  $\text{H}_2\text{SO}_4$ .

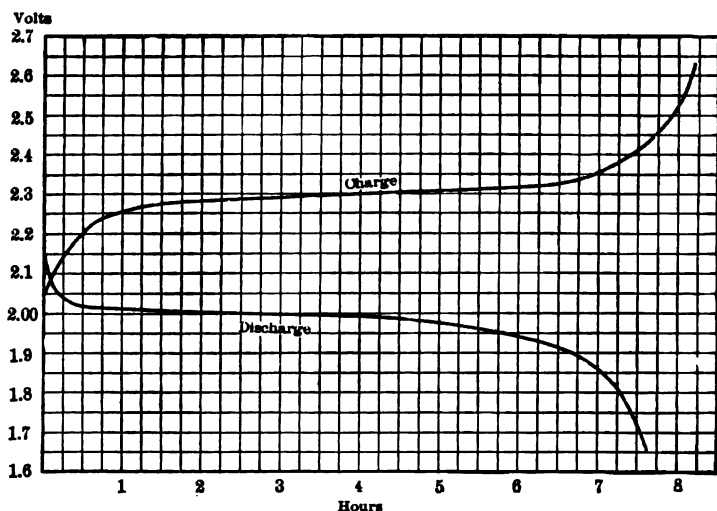


FIG. 1.

Dolezalek states that the E.M.F. of accumulators is dependent on the reduction of super oxide and oxydization of sponge lead to the extent of 40% or .8 volt; on acid concentration 40% or .8 volt, and on sulphatation of the oxides 20% or .4 volt.

Prof. Ayrton has found that when the active material on the peroxide plate is converted into sulphate to the extent of 69% of the total, the cell loses its E.M.F. entirely. This he attributes to the formation of a surface layer of sulphate, and also to the formation of peroxide on the negative plate.

The requirements which must be fulfilled by a battery to

give a discharge curve, which shall fall off but little, are: Plenty of electrolyte, thin layer of porous active material and complete reduction of the sulphate to Pb and  $\text{PbO}_2$  on previous charge.

In general, the behavior of a battery is as follows: On charge, the voltage begins at about 2 volts and rises to about 2.5 volts; before this point is reached, however, at about 2.3 volts, the evolution of gas begins. If charge be sufficiently prolonged, the voltage will rise as high as 2.8 though it is never advisable to do this in practice, except in certain rare instances for the reduction of sulphate, which will hereafter be mentioned.

On opening the charging circuit, the voltage falls quickly, finally dropping down to 2.1 volts, or such a value as is normal for the temperature and acid concentration of the

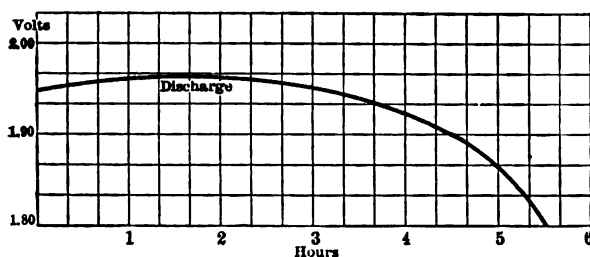


FIG. 2.

cell. On beginning discharge the voltage drops still further, reaching about 2.05 volts.

Within 10 or 15 minutes after beginning discharge, the voltage will fall to 2 volts, and, from then on, it goes down very slowly until it reaches a value of about 1.9, after which comes the rapid decrease.

After a long period of rest after having been fully charged, if the cell be discharged, the voltage does not begin to drop off at once, but on the contrary it rises slightly. Several cycles of charge and discharge are necessary to bring the battery back to its original condition, such that the voltage at beginning of discharge is high, rapidly falling during the first few minutes.



Fig. 2 shows the curve of discharge of a cell which has been allowed to stand idle for some time after being fully charged.

The maintenance of the voltage and consequently the capacity of the cell, depends on both the positive and negative plates and, therefore, if one be fully charged or fully reduced, and the other is only imperfectly charged, the capacity is small, being equal only to that of the least efficient plate; the battery is quickly discharged, and the voltage curve falls rapidly. It is necessary that both the positive and negative elements should be completely charged. The voltage of the battery is not always an indication of the state of charge and in order to determine the condition of the two plates, it is necessary to test them independently. This is done by immersing a piece of metal, either zinc or cadmium, in the electrolyte and observing the voltage between it, and the positive and negative elements.

Zinc is hardly used at all now, owing to the fact that pure zinc is difficult to obtain and it is soluble in the electrolyte, when impure. If any portion be dissolved it has a tendency to deposit, during charge on the negative plate, and erroneous readings would therefore result. With reasonable care, however, there is no reason why zinc should not be satisfactory in ordinary practical work, when cadmium is not available.

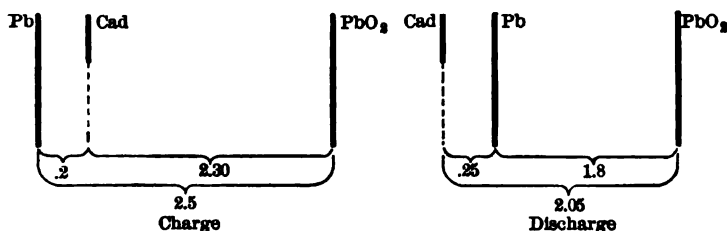
In using cadmium, which also must be free from marked impurities, the surface of the metal should never be scraped bright, but it should be "aged," that is, slightly oxydized. The reason of this is, that there is a difference of potential between bright cadmium and cadmium oxide, and the bright surface oxydizes so quickly that it would be necessary to scrape the test piece after each reading, if comparable results are to be obtained.

The cadmium must not come in contact with any of the plates or connections and the best way to obviate the possibility of such contact, is to cover it with rubber and perforate the covering with numerous small holes.

When a battery is discharged, that is, down to 1.8 volts—the voltage between the cadmium test piece and the positive

plate should be about 2.05 and between the cadmium and the negative plate .25, the cadmium being positive to both the elements in the voltaic sense. The voltage of the cell =  $2.05 - .25 = 1.8$ , the cadmium negative reading being subtracted from the positive reading, when both readings are in the same direction.

These readings must be made while the cell is discharging at normal rate. When the battery is fully charged, and the normal charging current is still passing in, the voltage between the cadmium and the positive plate should be about 2.35 and the voltage between the cadmium and the negative, .18 to .20, the cadmium being positive to the positive plate and negative to the negative plate; that is to say, voltaically considered, the negative plate becomes more highly electro-



FIGS. 3 AND 4.

positive and instead of being negative to the cadmium, as it is when discharged, it becomes positive to it.

Figures 3 and 4 show the conditions which obtain; figure 4 being that of discharge and figure 3 being that of charge.

The positions of the respective elements indicate their voltaic relations; the left being the positive side.

At end of discharge, the cadmium is positive to the peroxide plate, and the voltage between them being about 2.05. It is also positive to the sponge lead plate, the voltage between these two being about .25.

The voltage between the plates is obviously the *difference* of the cadmium readings which is 1.8.

In figure 3 it is seen that at the end of charge the cadmium is still positive to the peroxide plate, and the potential dif-

ference between them has increased. The sponge lead element has changed so that the cadmium is no longer positive to it, but negative, as shown. The voltage between the cadmium and positive is 2.32; between cadmium and negative—reading in the opposite direction, however—.18; and the voltage between the plates is the *sum* of these two or 2.5. Therefore it will be seen that the voltage between the battery plates is the sum of the two cadmium readings whenever the readings are in opposite directions, or the connections to the voltmeter have to be reversed after making one reading before the other can be made.

Conversely, when both the cadmium readings are in the same direction, the voltage of the cell is equal to their difference. In making all three readings, the sum or the difference of the two cadmium readings, as the case may be, should be equal to the observed voltage of the cell, though it is somewhat difficult in practice to measure these voltages accurately enough to make them check exactly, because of the small deflection produced between the cadmium and the negative plate.

Instances have come under the author's observation where cells on charge have shown as high as 2.5 volts and the reading between the cadmium and negative plates practically zero, showing that though the positives were fully charged the negatives were not, and these cells showed little or no capacity. On continuing the charging current for some time, the negatives were finally reduced to lead sponge and the battery then showed full capacity.

Under the action of rapid discharge, negative plates are sometimes peroxidized and it is then somewhat difficult to reduce the peroxide to lead sponge.

Fitz-Gerald accounts for this peroxidization by action of the evolved oxygen and previously formed persulphuric acid ( $\text{H}_2\text{S}_2\text{O}_8$ ), which travels to the negative plate, this electrode being the anode when discharge takes place.

The evolution of fixed gases is also an indication of complete charge, provided the rate of charge is not excessive.

Free gases are given off, when the quantities of oxygen and hydrogen evolved are in excess of the amount required

to combine with the lead sulphate on the plates and their release shows that all, or nearly all, of the sulphate is reduced. If, however, the current rate be too high, the gases will be liberated more rapidly than the sulphate can com-

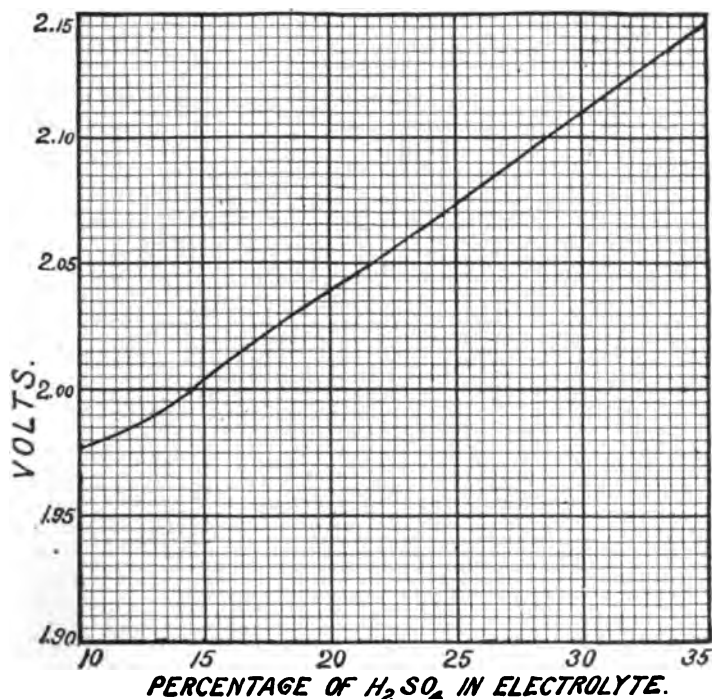


FIG. 5.

bine with them, and the excess will pass off in the form of free gases.

The voltage of a cell is further dependent on the density of the electrolyte, the internal resistance and the temperature. Figure 5 is a curve showing the increase of voltage with increase of electrolyte density.

Dolezalek has shown that the alteration in E.M.F. with respect to variation in acid concentration, corresponds exactly to the alteration in free energy to which two mole-

cules of  $H_2SO_4$  are subjected, when brought from one concentration to another.

The E.M.F. at various electrolyte densities, may be calculated by the following formula, due to Dr. Streintz:

$$E = 1.850 + .917 (S-s).$$

$E$  = E.M.F. in volts.

$S$  = Specific gravity of electrolyte.

$s$  = " " " water.

The two specific gravities being taken at the temperature of observation.

This formula may also be written:

$$E = 1.850 + .00057 z.$$

Where  $z$  = grams of  $H_2SO_4$  per litre of electrolyte.

These formulae do not hold for the extremes of concentration—zero or 100 per cent. but are correct for densities of from 1.005 to 1.650.

The effect of alteration of internal resistance is to vary the internal drop and consequently change the voltage of the cell. This effect, however, is always so small as to be negligible in practice.

With increasing temperature, the charging voltage increases while the discharging voltage is increased. This matter is treated in detail in a succeeding chapter.

In determining watt hour input or output of a cell, the *average* voltage multiplied by the ampere hours gives the desired result. This average voltage is obtained by taking the area enclosed by the curve, the extreme ordinates and the base line, and dividing by the length or by summation of ordinates, or any other method by which the average ordinate of any curve is obtained.

## CHAPTER IV.

### ON QUANTITY AND DISTRIBUTION OF ACTIVE MATERIAL.

---

The weight of peroxide or sponge lead necessary for a given output, depends on

- (1) The disposition of the active material.
- (2) Its density.
- (3) Its thickness.
- (4) The rate of discharge or current density per unit area of the electrolyte between the plates.

The theoretical weight of metallic lead required on either element to form sufficient active material for one ampere hour of discharge is 59.39 grains = .135 ounces avoirdupois, which will weigh .156 ounces when converted into peroxide. This theoretical quantity is calculated from the fundamental equation  $\text{Pb} + \text{PbO}_2 + 2\text{H}_2\text{SO}_4 = 2\text{PbSO}_4 + 2\text{H}_2\text{O}$ . In practice, however, the weight of active material per element is from 4 to 6 times the theoretical, for the reason that it is impossible to reduce all the active material or cause every particle to be penetrated by the current. Experiments of Fitzgerald, Reckenzaun and Sellon show that from .50 to .80 ounce of spongy lead is required per ampere hour, and from .53 to .86 ounce of metallic lead converted into peroxide for the same capacity. Fitzgerald states that the latter figure is required only when the contact between conducting grid and material is defective. As a matter of fact, when certain portions of the peroxide or sponge lead are not in contact with the grid, those portions become inactive and should no longer be classed as active material. If sections of the layer should be removed at those spots where it had lost contact, the capacity of the plate would be practically unchanged and the weight of the active material decreased. Any figure, therefore, based on deficient

contact, is erroneous, as it leads to infinity as a limit when the contact is totally eliminated.

The weights given are for practical discharges which end when the voltage falls to 1.80.

A given weight of metallic lead will form 1.155 times its weight of lead peroxide or will increase 15.5 per cent. Conversely to produce a given weight of peroxide .866 times or 86.6 per cent. of the given weight of metallic lead is required.

$$\text{PbO}_2 \times .866 = \text{Pb}$$

$$\text{Pb} \times 1.155 = \text{PbO}_2$$

Similarly the relations between lead oxide (litharge) and metallic lead are

$$\text{Pb} \times 1.075 = \text{PbO}$$

$$\text{PbO} \times .93 = \text{Pb}$$

and between red lead (minium) and metallic lead

$$\text{Pb}_3\text{O}_4 \times .906 = \text{Pb}$$

$$\text{Pb} \times 1.104 = \text{Pb}_3\text{O}_4$$

If weight of lead peroxide be reduced to that of litharge or the converse, the following will be the relation:

$$\text{PbO}_2 \times .937 = \text{PbO}$$

$$\text{PbO} \times 1.067 = \text{PbO}_2$$

If lead peroxide be converted into lead sulphate or vice versa, the changes in weight become

$$\text{PbO}_2 \times 1.275 = \text{PbSO}_4$$

$$\text{PbSO}_4 \times .785 = \text{PbO}_2$$

Fitzgerald gives the following practical rule for weight of active material per ampere hour for each of a pair of plates:

Long discharge, 8 to 10 hours...	.53 oz. avoir.
Moderate " 5 " ..	.60 " "
Quick " 3 " ..	.70 " "
High rate " 2 " ..	.80 " "
" " " 1 " ..	1.00 " "

He explains the necessity of increasing the amount of active material with increase of discharge rate, by the fact that a battery, having a given weight of active material on the plates will deliver fewer ampere hours at high rates than at low rates of discharge, and therefore an increase of active material is required for high rates if the capacity is to remain constant.

With this theory the author cannot agree, as decreasing capacity at high discharge rates is caused by several factors which are related to current density, exposed surface and electrolyte circulation rather than to the absolute quantities of peroxide and lead sponge present.

On rapid discharge, the inability of the acid to circulate from the inside of the pores to the surrounding liquid, soon brings down the voltage to the minimum allowable value before the normal capacity has been expended. Also the loss from internal resistance is increased.

As is well known, a battery which has been rapidly discharged has extraordinary recuperative power. If it be allowed to stand a short time a further discharge may be taken from it which will be greatly in excess of the recuperative discharge if the cell be first discharged at a low rate.

These considerations lead to the conclusion that the increasing of active material without increasing the area over which it extends, would in no wise produce a proper plate for rapid discharges, for it would increase the thickness of the active material, while a thin layer is most suitable for rapid discharge rates. The same quantity of active material spread over a greater surface would be more nearly in accordance with the requirements of the case.

Dr. Sieg describes some experiments made to determine the influence of the thickness of the layer of active material on the battery capacity. The results are shown by the curves in Fig. 6, in which the ordinates represent capacity in ampere hours per kilogram of element, and the abscissæ are plotted to correspond with different rates of charge.

These curves do not completely represent the true difference in capacity of thin and thick plates per unit of weight, of active material, for the reason that the curves assume the



proportion of grid and active material weight to be the same in plates of different thicknesses, which is not true in practice. The curves show, however, that the thinner the layer

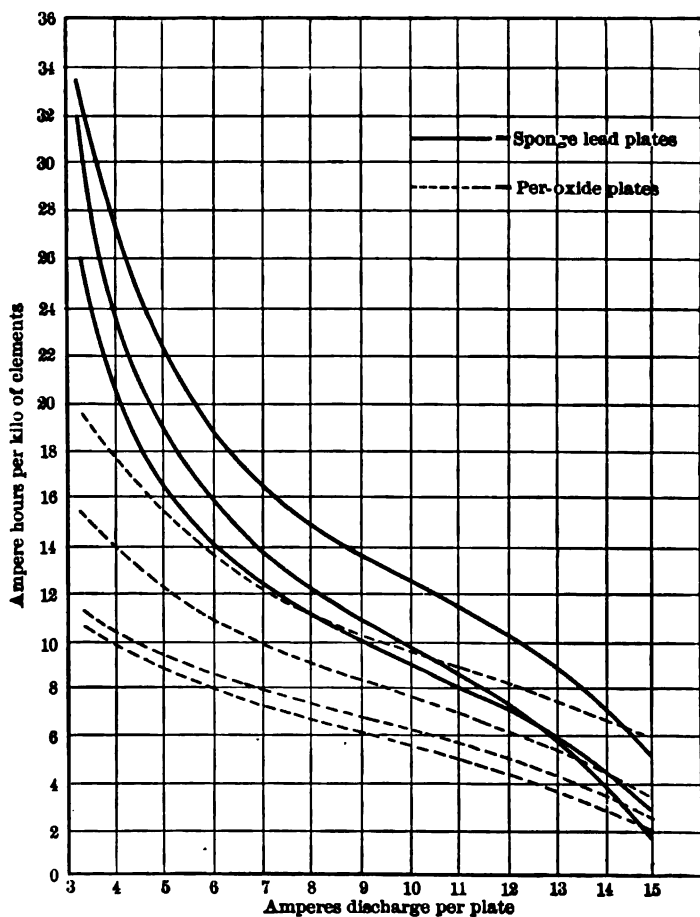


FIG. 6.

of active material the greater is the capacity for a given weight of element.

The full lines represent capacity of the negative or sponge lead elements, and the dotted lines show the capacities of the positive or peroxide elements.

It is of interest here to note the ratios of the weight of active material to weight of elements in the various types of batteries on the market.

The capacity per pound weight of elements is from 2.5 to 4 ampere hours in station batteries and from 4 to 6.5 ampere hours for traction cells. Allowing .56 ounce weight of lead which passes into active material per ampere hour on each plate, this would make  $.56 \times 1.115 = .644$  ounce, active material = 1.288 or say 1.3 oz. = .08125 pounds active material total in the battery per ampere hour.

Assuming 2.5 ampere hours per pound of element, there would be  $.08125 \times 2.5 = .221$  pounds active material per pound of element, or 22 per cent. of the total weight would be active material. Similarly, in a cell delivering 4 ampere hours per pound of element, the percentage of active material is 32.5 per cent. and in one delivering 6.5 ampere hours per pound, the percentage is 52.8 per cent.

In a properly designed battery, the durability will be greater the less the capacity per pound weight. Where the capacity per pound of cell is high, the layer of active material must be very thick, the quantity of electrolyte small and its density high. These two latter conditions are detrimental, as will be presently shown.

Of course, the greater the weight per ampere hour of capacity, the greater is the cost of the battery and therefore battery durability must be paid for.

## CHAPTER V.

### THE ELECTROLYTE.

---

The electrolyte should be of sulphuric acid made from sulphur. Acid made from pyrites should never be used as it is liable to contain injurious substances.

It should be diluted with sufficient pure, distilled water to bring to the required density, the acid in every instance being poured into the water, and never the water into the acid. The reason of this is that on dilution, a chemical combination is formed and not a mere mechanical mixture, and heat being liberated, the liquid becomes hot. If the water be poured into the acid, the chemical combination between the larger quantity of concentrated acid is more rapid than if the reverse method be pursued, and the acid be poured into the water.

Lately, it has become customary for sulphuric acid manufacturers to produce a low concentration acid, especially for electrolyte, and they claim that this is superior to that made by mixing in small quantities at the point of using. That it is more convenient, more likely to be of exactly the proper density, and carefully prepared is obvious, but electrolyte mixed on the spot is always much cheaper, both as to original cost and transportation, the weight being over three times as great for the dilute electrolyte as for an equivalent quantity of concentrated acid.

The amount of dilution or specific gravity of electrolyte, when the batteries are fully charged, should be about 1.210 to 1.240 at 60° F. for power station cells, though in motor car batteries 1.260 is often used. The abstraction of the  $\text{SO}_2$  on discharge which combines with the lead oxide to form lead sulphate, causes a gradual diminution of the specific gravity of the liquid by a definite amount, as will presently be shown.

The final density on discharge should not fall below 1.150, and 1.185 to 1.195 is usual practice.

In mixing the acid and water, the liquid becomes hot and must be allowed to cool before using. The vessel in which the mixing is done, should be of glass, glazed earthenware or lead, and the liquid should be stirred with a clean wooden stick, the acid being added to the water slowly.

After cooling, the specific gravity will be found greater than while hot, and the careful addition of a little water or

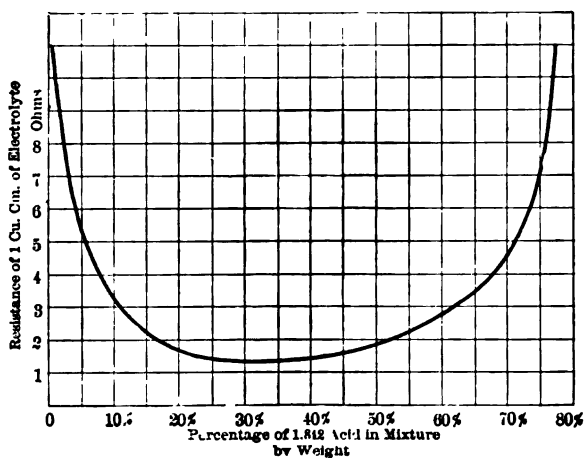


FIG. 7.

acid will probably be necessary to bring the liquid to a proper density.

The density of the electrolyte has an important bearing on the operation of the battery. If it be too high, sulphation is facilitated and the plates are liable to rapid depreciation. The E.M.F. of a battery, however, varies with the density of electrolyte, as has been previously indicated.

The resistance of dilute  $H_2SO_4$  is least at a density of about 1.260, rising if the gravity be either increased or decreased.

Figure 7 is a curve of variation of electrolyte resistance with density, and figure 8 gives also the resistance at vari-

ous densities and four different temperatures, but shows only the working portions of the curves. These curves show that the temperature coefficient is negative, the resistance decreasing with increase of temperature.

The electrolyte should be free from chlorine, nitrates, acetates, iron, copper, arsenic, mercury and the slightest trace of platinum. Mercury alone has no injurious effect unless it be present in sufficient quantity to amalgamate the plates, but in combination with another metal may cause local action, as explained in Chapter VII.

Mr. Rudolph Heinz gives the following as the limiting values of the percentages of iron, chlorine and nitrogen allowable in good electrolyte, concentrated acid being 100 per cent.: iron, .01 per cent.; chlorine .002 per cent.; nitrogen, in any form, as am-

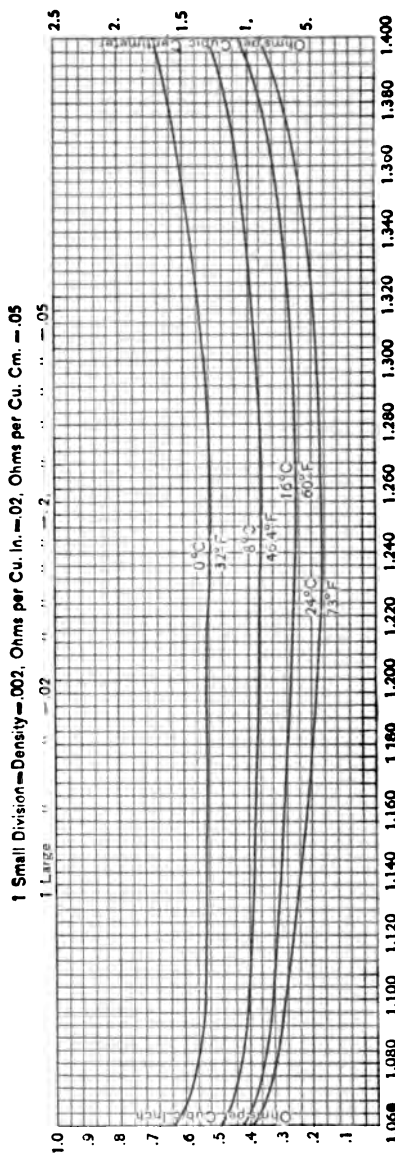


FIG. 8.

monia, nitric acid, etc., .1 per cent. He also states that it should be free from organic substances.

The electrolyte should be tested for impurities before putting into batteries and also occasionally after being in use.

If no objectionable elements are revealed on the first tests, and later nitrogen, chlorine or acetate is found, it may be assumed that the acids used in formation were not thoroughly removed.

Batteries, however, which have been installed in ice making and cold storage plants, have often gone to pieces owing to absorption of ammonia, which has a strong affinity for water, and which turns into nitric acid on passage of current through the cells, in a direction opposite to that in which it flowed when the ammonia was absorbed.

The following tests are sufficient for the determination of the suitability of the acid or electrolyte for battery purposes:

#### *Platinum.*

A chemical test for traces of platinum is so complicated and difficult as to make it practically impossible for any one but an experienced chemist to carry it through, and if the electrolyte be suspected, a sample should be analyzed by some one having the necessary skill and appliances.

A good rough test for traces of platinum is to pour the electrolyte into a cell in which the regular battery plates are immersed. If gassing takes place for some time on open circuit, it is an indication of the presence of platinum.

Since the smallest trace will cause the cell to discharge, and the higher grades of acid are often passed through platinum stills, great care must be used to procure electrolyte which is free from it.

#### *Iron.*

Take a sample of dilute acid—about one part of acid to two of water, and neutralize with ammonia or caustic potash solution. Then boil with hydrogen peroxide using a quantity of about one-thirtieth the amount of the solution

being tested. All iron present is changed into the ferric state. Take now a sample of the liquid and put into a test tube. Add ammonia or caustic potash solution until the mixture becomes alkaline. If there is much iron present a brownish red precipitate will form on making the liquid alkaline.

A second test should be made for traces of iron, which is done by taking a second sample of the liquid which has been neutralized and boiled with hydrogen peroxide, and adding a few drops of red prussiate of potassium ( $K_2FeO_4$ ). If any traces of iron are present the liquid will turn red. This is a very delicate test.

### *Chlorine.*

To the dilute acid, add a few drops of nitrate of silver solution made by dissolving 20 grams of silver nitrate in 1,000 cu. cms. of water. If chlorine is present, as chlorides, the solution will turn white owing to the formation of a precipitate of silver chloride.

Silver chloride is soluble in ammonia and may be re-precipitated by nitric acid.

### *Nitrates.*

1. Put 25 cu. cms. of dilute acid in a test tube, and add 10 grams of strong ferrous sulphate solution. Carefully pour down side of a test tube 10 cu. cms. of chemically pure, concentrated sulphuric acid.

If nitric acid be present, it will be indicated by a stratum of a brown color which will form between the solution and the concentrated acid. The depth of the color will indicate the relative proportion of nitric acid present.

2. If the electrolyte be first tested for chlorine and found free of it, the following test is an excellent one for nitrates:

Place some chemically pure copper filings in a test tube and pour in the electrolyte to be tested. Close with a

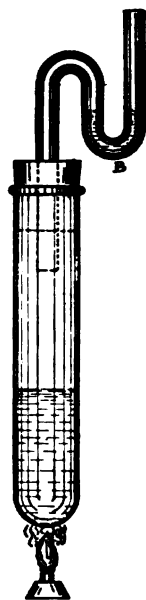


FIG. 9.

stopper through which is passed a glass tube having a double bend, as shown in Figure 9. Solution of ferrous sulphate is poured into the bend of the tube as indicated at "B."

On heating the tube over a bunsen flame, the nitrate vapors will attempt to pass out of the tube, but will be absorbed by the iron proto-sulphate, which latter will turn to a blackish brown.

#### *Copper.*

Ammonia solution added to the electrolyte produces a bluish-white precipitate if there is any copper present. When an excess of ammonia is added and the liquid becomes alkaline, the precipitate disappears and the liquid becomes a dark blue color. This is a delicate test, and will show the presence of 0.002 per cent. of copper.

#### *Mercury.*

The presence of mercury in the electrolyte is indicated by a black precipitate when lime water is added, or by an olive green precipitate if solution of potassium iodide be added.

#### *Arsenic.*

Pass sulphuretted hydrogen ( $H_2S$ ) through a warm, dilute solution of electrolyte. If a yellow precipitate forms, it is probably arsenic, but may be sulphur, caused by oxidation of  $H_2S$  by ferric salts or nitrates. Take two test tubes and put a portion of the yellow liquid in each. Add to one ammonium sulphide, to the other ammonium carbonate. If the yellow precipitate is an arsenic compound, it will be dissolved by the ammonium sulphide, but not by ammonium carbonate.

#### *Acetic Acid.*

Add ammonia to solution until it becomes neutral; then add ferric chloride ( $Fe_2Cl_6$ ). If the solution turns red, and is afterward bleached by the addition of hydrochloric acid there is acetic acid present.



The foregoing tests are given in the order of their importance. If the first four tests indicate freedom from platinum, iron, chlorine and nitrates, it is reasonably safe to assume that the electrolyte is suitable for use and the others may be omitted, though it is better to make all the tests indicated.

Plate I shows a set of curves and co-ordinates by means of which the density of mixtures for any given percentage of acid, up to 40 per cent. may be determined, for any temperature between 32° and 120° Fahrenheit. Conversely, the percentage of acid in a mixture of given density and temperature may be found, as may also the change of density of any mixture with change of temperature.

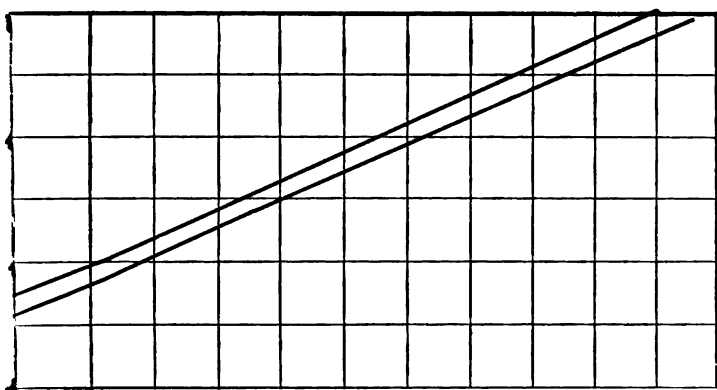
1. To find the density of liquid having a given percentage of acid: Read off the percentage on the vertical scale at the left of the upper half of the sheet. Follow horizontally over to the intersection of the horizontal line with the curve representing the density of the acid entering into the mixture. From the intersection thus found, follow vertically down to the horizontal scale marked "specific gravity," where the density be shown for a temperature of 60° F. or 15.5° C.

If the temperature of the mixture is above or below 60°, follow the vertical line down past the horizontal scale until it intersects the diagonal line on which is marked the required temperature. This gives a second intersection from which a horizontal line must be followed, toward the left, until it crosses the vertical scale on which densities are marked. The intersection of this horizontal with the vertical scale, shows the density of the mixture for the given percentage of acid and temperature.

It is here to be noted that commercial acid is 1.835 specific gravity and this should be the curve used for practical mixing.  $H_2SO_4$ , however, is 1.842 specific gravity, and this curve should be always used to determine percentages and densities for electro-chemical calculations.

2. To find percentages of acid in mixture of given density and temperature:

Read the given density on the one of the lower vertical scales on which this density is found. Follow horizontally





to the right to intersection of the horizontal with the diagonal line of given temperature. Take a vertical from this intersection upwards until the curve is intersected. Follow a horizontal from the last intersection, over to upper vertical scale on the left. The point thus located gives the percentage of acid (1.835 or 1.842 according to the curve used) required to produce the given density at the specified temperatures.

3. To find change of density with change of temperature:

Locate given density on one of the lower vertical scales. Follow horizontally to intersection with diagonal line of given temperature. From this intersection follow vertically up or down (according to whether the temperature at which the density is to be found, is higher or lower than observed temperature) to the intersection of vertical with the diagonal line of temperature at which the density is required. From the intersection thus found, follow back horizontally towards the left to scale on which the first reading was taken. The point located by the intersection of the last horizontal and the vertical scale, will show the density at the changed temperature.

4. To find the temperature of electrolyte, the density at any other temperature being known, and density at changed temperature being given:

Follow a horizontal line from the known density reading on one of the lower vertical density scales, to the right, until it intersects the diagonal of the known temperature. Follow also a similar horizontal from the observed density at changed temperature. At the point of intersection of the second horizontal, with a vertical which is in line with the intersection of the first horizontal and the temperature line, will be found the temperature of the liquid.

Any intersection which falls between the temperature diagonals must have its value estimated by its relative position between them.

#### EXAMPLES:

1. What is specific gravity of mixture containing  $36\frac{1}{2}$  per cent. of 1.835 acid at  $60^{\circ}$ ? Ans. 1.2688.

2. What is specific gravity of mixture containing 32 per cent. of 1.835 acid at 90° F.? Ans. 1.224.

3. If a mixture contains 30 per cent. of 1.835 acid, what is the equivalent percentage of 1.842 acid? Ans. 29.2 per cent.

4. If a mixture shows a density of 1.180 at 85° F., what percentage of 1.835 acid does it contain? What percentage of 1.842 acid? Ans. 1.835 acid, 26 per cent. 1.842 acid, 25.4 per cent.

NOTE:—As there is no temperature line between the 80 and 90 degree lines, a point must be taken half way between these two for 85 degrees. For 82½ degrees, a point ¼ the distance from the 80 to the 90 line would be taken. Division by the eye is accurate enough for all practical use.

5. A mixture shows specific gravity of 1.290 when at 100° F. What will be its density at 40°? Ans. 1.3075, say 1.308.

6. What is the temperature of a mixture which shows a density of 1.256, its density previously noted at 40° being 1.276? Ans. 110°.

Following are tables giving the constants of electrolytes of various densities at 60° F., from which preceding curves were plotted.

TABLE I.  
SULPHURIC ACIDS.  
MIXTURE BY WEIGHT.

Sp. Gr.	Wt. in lbs. per cubic foot	Per cent. of 1.835 acid	Lbs. of 1.835 acid in 1 cu. ft.	Per cent. of 1.842 acid
1.000	62.37	0.00	0.00	0.000
1.007	62.81	1.00	0.63	0.935
1.014	63.24	2.50	1.58	2.337
1.021	63.68	3.66	2.33	3.422
1.028	64.12	5.00	3.21	4.675
1.036	64.62	6.00	3.88	5.610

## SULPHURIC ACIDS—CONTINUED.

Spr. Gr.	Wt. in lbs. per cubic foot	Per cent. of 1.835 acid	Lbs. of 1.835 acid in 1 cu. ft.	Per cent. of 1.842 acid
1.043	65.05	7.00	4.55	6.545
1.051	65.55	8.00	5.24	7.480
1.058	65.99	9.00	5.94	8.415
1.066	66.49	10.25	6.82	9.584
1.074	66.99	11.50	7.70	10.752
1.082	67.48	12.50	8.44	11.637
1.090	67.98	13.60	9.25	12.716
1.098	68.48	14.70	10.07	13.744
1.107	69.04	16.00	11.05	14.960
1.115	69.54	17.00	11.82	15.895
1.124	70.10	18.25	12.79	17.064
1.133	70.67	19.60	13.85	18.326
1.124	71.23	21.00	14.96	19.635
1.151	71.79	22.00	15.79	20.570
1.160	72.35	23.25	16.82	21.739
1.169	72.91	24.50	17.86	22.907
1.179	73.53	26.00	19.12	24.310
1.188	74.10	27.25	20.19	25.479
1.198	74.72	28.50	21.30	26.647
1.208	75.34	30.00	22.60	28.050
1.218	75.97	31.25	23.74	29.219
1.229	76.65	32.75	25.10	30.621
1.239	77.28	34.00	26.28	31.790
1.250	77.96	35.50	27.68	33.192
1.261	78.65	37.00	29.10	34.595
1.272	79.33	38.37	30.44	35.876
1.283	80.02	39.75	31.81	37.166
1.295	80.77	41.25	33.32	38.569
1.306	81.46	42.62	34.72	39.850
1.318	82.20	44.00	36.17	41.140
1.330	82.95	45.50	37.74	42.542
1.342	83.70	47.00	39.34	43.945
1.355	84.51	48.50	40.99	45.347

## SULPHURIC ACIDS—CONTINUED.

Spr. Gr.	Wt. in lbs. per cubic foot	Per cent. of 1.835 acid	Lbs. of 1.835 acid in 1 cu. ft.	Per cent. of 1.842 acid
1.368	85.32	50.00	42.66	46.750
1.381	86.13	51.50	44.36	48.152
1.394	86.94	53.00	46.08	49.555
1.408	87.82	54.50	47.86	50.957
1.421	88.63	56.00	49.63	52.360
1.436	89.56	57.50	51.50	53.762
1.450	90.44	59.00	53.36	55.165
1.465	91.37	60.50	55.28	56.567
1.479	92.25	62.00	57.20	57.970
1.495	93.24	63.50	59.21	59.372
1.510	94.18	65.00	61.22	60.775
1.526	95.18	66.50	63.29	62.177
1.542	96.17	68.00	65.40	63.580
1.559	97.23	69.70	67.77	65.169
1.576	98.30	71.30	70.09	66.665
1.593	99.36	73.00	72.53	68.255
1.611	100.48	74.60	74.96	69.751
1.629	101.60	76.20	77.42	71.247
1.648	102.79	77.87	80.04	72.808
1.666	103.91	79.50	82.61	74.332
1.686	105.16	81.30	85.50	76.015
1.706	106.40	83.00	88.31	77.605
1.726	107.65	85.00	91.50	79.475
1.747	108.96	87.00	94.80	81.345
1.768	110.27	89.00	98.14	83.215
1.790	111.64	91.62	102.29	85.665
1.801	112.33	93.12	104.60	87.067
1.807	112.70	94.00	105.94	87.890
1.812	113.01	94.70	107.02	88.544
1.818	113.39	95.66	108.47	89.442
1.824	113.76	96.80	110.12	90.508
1.830	114.14	98.33	112.23	91.939
1.835	114.45	100.00	114.45	93.500

TABLE II.  
APPROXIMATE BOILING POINTS.

Acid density	Deg. F.	Acid density	Deg. F.
1.526	291	1.768	423
1.706	378	1.790	446
1.726	388	1.812	475
1.747	403	1.835	522



## CHAPTER VI.

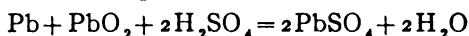
### ON THE QUANTITY OF ELECTROLYTE.

According to the fundamental equation of the lead storage battery there is a definite amount of  $\text{SO}_3$  abstracted from the electrolyte on discharge, causing the density of the liquid to decrease as discharge goes on.

As the electrolyte decreases in density the E.M.F., capacity and conductivity likewise decrease and as these should be maintained as high as possible, it follows that the acid density should not fall too low towards the end of discharge. The initial density, *i. e.*, that at beginning of discharge, must not be over 1.240 or 1.245, as higher densities cause sulphation and deterioration.

It is obvious that the greater the quantity of electrolyte present and entering into the chemical action the less will be the change in density.

Going back to the equation



it is seen that for each unit of current discharged, two electro-chemical equivalents of  $\text{H}_2\text{SO}_4$  must be decomposed.

The ampere hour equivalent of sulphuric acid is 1.826 grams. Therefore, for each ampere hour of discharge  $2 \times 1.826 = 3.652$  grams will be decomposed and for  $Q$  ampere hours  $Q \times 3.652$  grams =  $Q \times .129$  ounces avoirdupois will be decomposed.

$\text{H}_2\text{SO}_4$  is partly water even in its concentrated form and may be considered as  $\text{H}_2\text{O} + \text{SO}_3$ . The weight of water in the concentrated acid is calculated as follows: The molecular weight of  $\text{H}_2\text{SO}_4 = 98$  and of water is 18. Calling this quantity of water  $aq$ .

$aq = \frac{18}{98} = .1837 = \text{proportion of water in concentrated } \text{H}_2\text{SO}_4 \text{ of sp. gr. } 1.842.$

In A ounces of ounces of acid there are therefore  $A \times .1837$  ounces of water and  $A \times (1.00 - .1837)$  ounces of  $\text{SO}_3$ .

The following method of calculating the quantity of electrolyte is due to Fitz-Gerald:

Let  $N$  = percentage of  $\text{H}_2\text{SO}_4$  in the electrolyte at beginning of discharge.

Let  $Aq$  = weight of water in electrolyte.

Let  $n$  = percentage of  $\text{H}_2\text{SO}_4$  in the electrolyte at end of discharge.

Then:  $N : (100 - N) :: A : Aq$  ..... (3)

$$Aq = \frac{A \times (100 - N)}{N} \text{ ounces avoirdupois} \dots\dots\dots (4)$$

Now, after end of discharge, an amount of  $\text{H}_2\text{SO}_4 = A$  has been decomposed, the  $\text{SO}_3$  taken up and the  $\text{H}_2\text{O}$  remaining behind; that is  $(A - aq)$  has been taken up and  $aq$  left. Also  $Aq$ , the water mixed with the  $\text{H}_2\text{SO}_4$  to dilute it, is left behind, so that for a given quantity of  $\text{SO}_3$  that combines with the active material an amount of water =  $Aq + aq$  is released to still further dilute the electrolyte.

To prevent the density from falling below the desired amount, such that  $n$  is the percentage of  $\text{H}_2\text{SO}_4$  in the total remaining mixture, an additional amount of electrolyte must be present or  $x$  times the quantity of liquid that is decomposed.

(5)

$x(A + Aq) + A + Aq + aq$  = total amount of electrolyte required,  $x$  varying with  $n$ .

$$n : 100 :: xA : (x(A + Aq) + Aq + aq)$$

$$\frac{100}{n} = \frac{x(A + Aq) + Aq + aq}{xA}$$

$$\frac{100 \times A}{n} = x(A + Aq) + Aq + aq$$

$$\frac{100A}{n} - \frac{Aq + aq}{x} = A + Aq \text{ whence}$$

$$x = \frac{Aq + aq}{\frac{100A}{n} - A + Aq} \dots\dots\dots (6)$$

Substituting in equation (5)

$$W = \frac{Aq + aq}{\frac{100A}{n} - A + Aq} (A + Aq) + A + Aq + aq \dots (7)$$

W being the total weight of electrolyte.

If A be taken = 12.9 and the proper values of N, n, Aq and aq be substituted the result will be in ounces per 100 ampere hours. Aq becomes  $\frac{12.9 (100 - N)}{N}$  and

$aq = 12.9 \times .1837 = 2.36$  for this particular value of A.

If  $.129 \times Q$  be substituted for A, and corresponding values of Aq and aq found, the result will be in ounces for Q ampere hours.

If n be the unknown quantity, the equation may be written

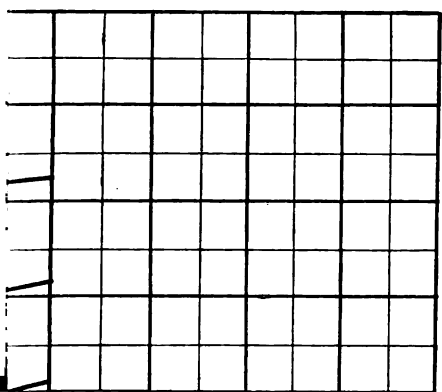
$$n = \frac{100A}{\frac{(Aq + aq)(A + Aq)}{W - A + Aq + aq} + A + Aq} \dots (8)$$

If any three of the four quantities W, N, n and ampere hours discharge be known, the fourth can be solved for. Usually N, n and ampere hours discharge are the known or assumed quantities, and W the one to be calculated.

In Plate II is shown a series of curves designed by the author for the use of a battery manufacturing company, and which give the relations between the ampere hours discharge; the initial density of electrolyte when battery is fully charged; the terminal density of electrolyte at any period of discharge, and the quantity of electrolyte in the cell.

Call Ampere Hours..... "A.H."  
 " Initial Density..... "I"  
 " Terminal " ..... "T"  
 " Quantity..... "Q"

The curves are calculated to show I., T. and Q. for 100 ampere hours, electrolyte at 60° C. Other discharges may be referred to the curves by proper corrections for temperature and discharge.





The vertical, left hand scale shows percentages of acid in the mixture of density 1.842, and the density corresponding thereto at 60° F. The lower horizontal scales show the quantity of electrolyte in ounces and pounds avoirdupois.

The separate curves are each for a given *initial* density and percentage of electrolyte.

1. To find quantity of electrolyte required (Q) when A.H., I, and T are given:

If A.H. = 100 and temperature = 60° F., follow horizontal corresponding to desired terminal density from vertical scale on left to curve of given I. From this intersection follow, vertically, downward to lower scale where Q is read off.

If temperature is other than 60°, refer to Plate I and find the equivalent density at 60° by method previously given, and use the corrected densities thus found as I. and T.

If A.H. is some discharge other than 100 ampere hours, the actual quantity =  $\frac{Q \times AH}{100}$  in which Q = reading on lower horizontal scale.

2. If A.H., I and Q are given, to find T:

If A.H. = 100 and temperature = 60°, follow vertical from lower scale at point of given Q, to curve of given I. From intersection thus found, follow horizontally to left and read on vertical scale the value of T.

If temperature is not 60°, correct I for temperature as above explained, using the corrected value of I for locating curve. *After finding T*, correct this also for temperature.

If A.H. is some value other than 100, correct by formula  $\frac{100}{A.H.} Q = QC$ . Use this value QC as the starting point on the horizontal scale instead of Q, and proceed as before.

3. Given A.H., Q and T, to find I:

Take a vertical up from Q and a horizontal across from T. Their intersection will fall on a curve of I, which will show the I sought, if A.H. = 100 ampere hours. If the intersection falls between two curves of I, the value of the I sought must be estimated by its position with reference to the two curves between which it falls.

The before mentioned temperature corrections must be applied to  $T$  before beginning, and to  $I$  after obtaining the result.

If the A.H. is some value other than 100,  $Q$  must be corrected, and the value  $QC = \frac{100}{AH} Q$  used as the starting point on the horizontal scale.

4. If  $Q$ ,  $T$  and  $I$  be given, it is possible to determine the number of ampere hours taken out of a battery, provided proper temperature corrections of  $T$  and  $I$  be made; making these corrections and using the corrected values:

Follow a horizontal from  $T$  to  $I$ . From intersection of the horizontal with  $I$ , to follow a vertical down to a horizontal scale. Take the reading on this scale, at the intersection of the vertical, and call this  $g$ .

$$\text{Then } AH = \frac{Q \times 100}{g}$$

#### EXAMPLES:—

1. In a battery which is to give 100 ampere hours, how many ounces of electrolyte are required, if the density on beginning of discharge be 1.250 and the terminal density is to be 1.195, densities being taken at temperature at 60° F.? Ans. 145 oz.

2. If battery is to give 80 ampere hours on discharge, and the density is 1.265 before the beginning charge at temperature of 100° F., and a density of 1.185 be required at end of discharge, temperature being 70° F., how many ounces of electrolyte are required? Ans. 77.6 oz.

This problem is solved as follows: From Plate I the initial and terminal densities are corrected for temperatures, both being reduced to their equivalent at 60° F. The corrected temperatures are: 1.265 at 100° becomes 1.276 at 60°; 1.185 at 70° becomes 1.189 at 60°. Taking these at initial and terminal densities respectively, the weight of electrolyte for 100 ampere hours is found from the curve which is 97 oz. For 80 ampere hours the amount is  $\frac{97 \times 80}{100} = 77.6$  oz. It is to be noted that the value of the

initial density—1.276—has no curve. Therefore, a point on the horizontal line from the reading 1.189 on the left hand scale must be chosen between the curves 1.270 and 1.280, about .6 the distance from 1.270 towards 1.280. This can be divided by the eye closely enough for all practical purposes.

In succeeding problems the temperature of the mixture will be taken as 60°; it being understood that all densities must be properly corrected to this temperature if they differ from it.

3. Initial density 1.225, terminal 1.176, ampere hours discharge 210. What is the weight of electrolyte in the battery? Ans. 363 oz. The reading of 173 oz. is for 100 ampere hours, the quantity is  $\frac{173 \times 210}{100} = 363.3$  oz.

4. A battery cell contains 238 oz. of electrolyte of density 1.240 at beginning of discharge. Later the density becomes 1.200. How many ampere hours have been taken out of the battery? Ans. 116 ampere hours. In this the curve shows that 205 oz. are required to deliver 100 ampere hours; therefore the discharge due to 238 oz. would be  $\frac{238}{205} \times 100 = 116$  A.H.

5. A battery containing 240 oz. of electrolyte discharges 162 ampere hours, and the final density of electrolyte is 1.147. What was the density on beginning of discharge? Ans. 1.208. 240 oz. of electrolyte and 162 ampere hours gives  $\frac{240 \times 100}{162} = 148.2$  oz. for 100 ampere hours. The intersection of the vertical from 148.2 and the horizontal from 1.147, falls between the curves 1.200 and 1.210, near the latter. Dividing visually, the value is seen to be about 1.208.

6. A battery contains 113 oz. of electrolyte, density 1.245. What will be the density when 106 ampere hours are discharged? Ans. 1.164.  $\frac{113 \times 100}{106} = 106.5$ , which is the number of oz. per 100 ampere hours. Starting from



106.5 oz. and going up to a point about midway between the curves 1.240 and 1.250, the position of the horizontal line over to the vertical scale is located, and the value of the terminal density given.

TABLE III.

Time.	Amperes.	Volts.	Acid Density.	Decrease in Density.	Grams of $H_2SO_4$ Used.	
					Per Hour.	Per Amp. Hour.
8 <sup>57</sup> a. m.	4.00	2.01	1.2410			
9 <sup>57</sup>	4.00	2.00	1.2373	0.0037	7	1.75
10 <sup>57</sup>	4.00	1.99	1.2319	0.0054	10	2.50
11 <sup>57</sup>	4.00	1.98	1.2260	0.0059	10	2.50
12 <sup>57</sup> p. m.	4.00	1.97	1.2199	0.0061	11	2.75
1 <sup>57</sup>	4.00	1.95	1.2139	0.0060	11	2.75
2 <sup>57</sup>	4.00	1.935	1.2079	0.0060	11	2.75
3 <sup>57</sup>	4.00	1.915	1.2017	0.0062	11	2.75
4 <sup>57</sup>	4.00	1.89	1.1961	0.0056	10	2.50
5 <sup>57</sup>	4.00	1.855	1.1899	0.0062	11	2.75
6 <sup>57</sup>	4.00	1.835	1.1835	0.0064	12	3.00

TABLE IV.

DISCHARGE RATE.		Time of Discharge in Hours.	Capacity in Amp. Hrs.	Grams of $H_2SO_4$ used per Amp. Hr.
Amperes.	Amps. per Sq. Decm.			
5	2.94	6	30	2,560
4	2.35	9	36	2,705
3	1.76	14	42	2,855
2	1.18	24	48	3,083
1	0.59	59	59	3,269

After a little practice, the use of these curves will be found very simple, and nearly any problem in battery work, relating to electrolyte densities, etc., can be solved by mere inspection.

In practice, the variation in density of electrolyte with ampere hours discharged, does not conform to the theoretical unless the discharge rate is very low, and the higher the rate of discharge the less is the diminution in density.

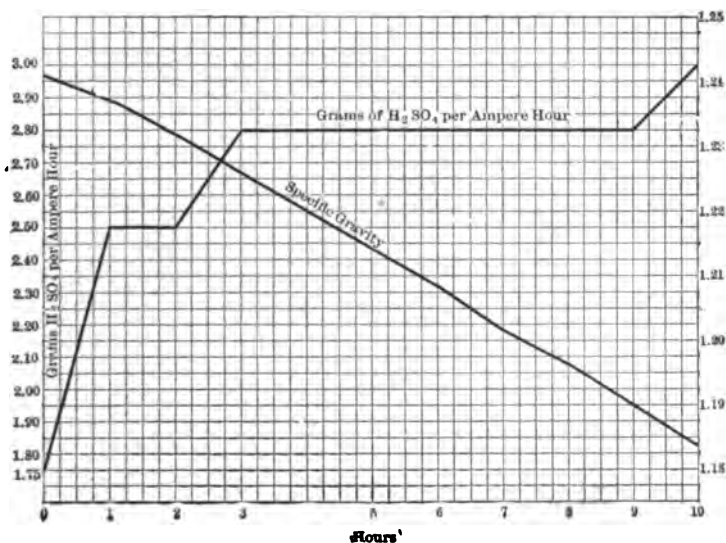


FIG. 10.

The results of some experiments conducted by Dr. A. Pfaff, of Germany, were published during the early part of 1901.\* These are shown in the tables III and IV, and expressed in curves, figures 10 and 11.

Table III and figure 10 show the changes actually observed in a cell discharging at a constant rate. Table IV and figure 11 show the variation with different discharge rates.

In Fig. 10, the broken line shows the grams of  $H_2SO_4$  abstracted from the electrolyte per ampere hour, at different stages of discharge. The curve marked "specific gravity"

\*Centralblatt für Accumulatoren. No. 5, Vol. II. March, 1901.

and which is referred to the scale on the right, shows the specific gravity of the remaining liquid.

Fig. 11 shows how the amount of  $H_2SO_4$  per ampere hour abstracted on discharge, will vary with the rate at which discharge takes place.

These experiments show conclusively that the theoretical laws do not hold except at discharge rates so low as to be impracticable. The calculations, however, are useful to de-

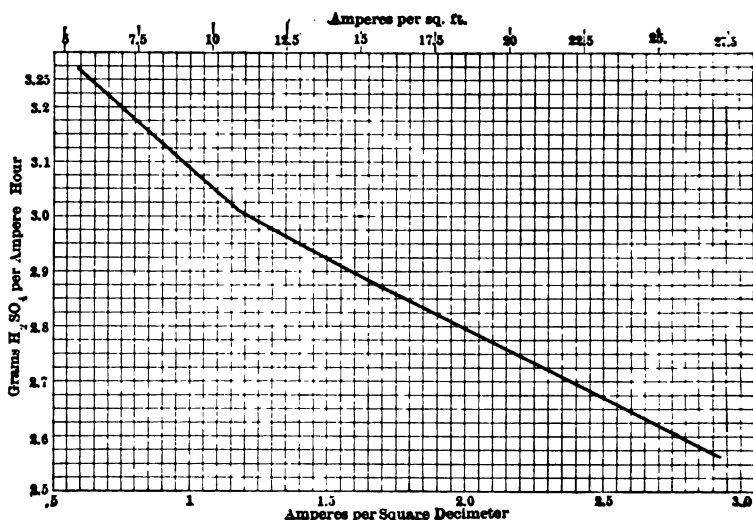


FIG. 11.

termine the limiting values of weight and terminal density in a cell of given capacity with electrolyte of given density.

The discrepancy between actual and theoretical results at high discharge rates is caused by the formation of the surface layer of sulphate which prevents diffusion of electrolyte into and out of the pores. The acid in the pores becomes highly dilute, giving up nearly all of its  $SO_3$  to the active material to form sulphate. If the outside acid and that in the pores could mix, after discharge, the resultant specific gravity would be the same for a given ampere hour output regardless of the rate at which discharge took place.

The question of change in capacity with increase in quan-

tity of electrolyte, has been investigated at length by Herr H. Wehrlin\* and the accompanying curves (Fig. 12) show the increase produced by the addition of electrolyte, these being plotted from readings made on actual experiments. The decrease of acid density as the discharge goes on, is also shown.

A good general rule is to use low concentration—not above 1.240—and provide enough acid to keep the terminal density well up—say to 1.190 to 1.200. If 1.200 electrolyte is

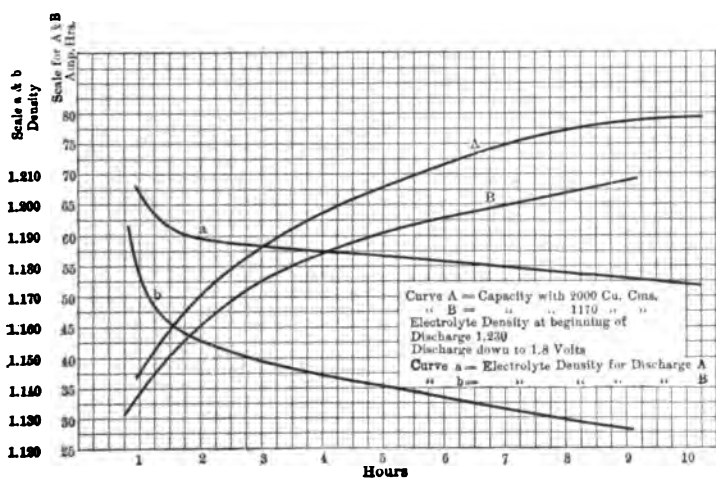


FIG. 12.

used, the terminal density should not fall below 1.158 or 1.160. Use the electro-chemical formula for the maximum and provide fully the quantity of electrolyte calculated.

The practice in this country varies from 10 to 20 lbs. of electrolyte per 100 ampere hours in station cells, and from 5 to 8 lbs. in automobile batteries.

The more electrolyte there is present, the better the performance of any given cell.

The reader may think it strange that in this discussion no use has been made of the term "degrees Beaume." The reason is that the author considers it utterly useless, and,

\*Centralblatt für Accumulatoren. No. 4, 1901.

in fact, an absurdity to make use of a system which means nothing, and which must be converted into specific gravity in order that it should have any meaning. The system has no place either in theory or practice, and the only rational system is the direct use of specific gravity values.

## CHAPTER VII.

### INTERNAL DISCHARGE.

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Internal discharge which takes place under certain conditions between the active material and the grid or portions of the active material and metallic impurities on the same plate which may be at different potentials, is termed "Local Action." The essential conditions which must be fulfilled in order that local action may take place, are: The electrolyte must be in contact with both the elements which form the active couple; the grid or metallic impurity and active material must be in contact with each other; the difference of potential between the two elements which form the local voltaic couple, must be sufficiently great to decompose the electrolyte.

The minimum E.M.F. which will decompose electrolyte, varies with the nature of the electrodes forming the couple. The following is a table of the voltages which are capable of decomposing the electrolyte when one of the electrodes is hydrogen, and the other the element given in the table:

Platinum sponge.....	.005	volt.
Or finely divided		
Gold.. ..	.02	"
Iron... ..	.08	"
Platinum (plates) .....	.09	"
Silver .....	.15	"
Nickel .....	.21	"
Copper.....	.23	"
Cadmium.....	.48	"
Tin .....	.53	"
Lead.....	.64	"
Zinc.....	.70	"
Mercury.....	.78	"

The internal discharge, or local action, occurs more often at the sponge lead electrode than at the peroxide plate. This self-discharge is most frequently due to impurities in the electrolyte.

The voltage between the sponge lead electrode and a hydrogen electrode, *i. e.*, a platinum plate covered with platinum sponge, in which hydrogen is occluded and around which a film of hydrogen is formed; in electrolyte of usual density is about .33 volts, and it therefore follows that if any of the substances in the table from platinum to copper, inclusive, whose voltages of dissociation are lower than this value, are contained in the acid and are deposited on the lead sponge, or appear as impurities in the active material, the conditions for local action will be present and self-discharge will take place.

The intensity of the local discharge will be inversely proportional to the values of the E.M.F.s required to decompose the electrolyte and therefore of the elements which will cause local action, platinum will have the most, and copper the least, effect.

It has been experimentally determined that if the solution contain one one-millionth of platinum, a rapid internal discharge of the negative plate will result.

Instances have occurred in which the acid used for electrolyte has been considered chemically pure having been distilled in platinum vessels and in these batteries the negative plates lost their capacity and rapidly disintegrated.

It has also been discovered that metals which possess a very slight capacity for producing self-discharge when present in the electrolyte alone, if in company with one or more other metals of the same character, will produce rapid internal discharge of the battery. No reason has ever been assigned for this peculiar phenomenon, but it is well known that two or more metals, of nearly any kind, in the electrolyte have a deleterious effect.

It is an unfortunate fact that the better the negative plate and the more porous the active material thereon, the greater is the danger from internal discharge.

In connection with this subject, it may be mentioned that

the negative plate, when charged, should never be permitted to become dry or exposed to the action of the atmosphere, as oxydization of the sponge lead will take place very quickly, with the result that the plates become very much heated, they rapidly harden and it is very difficult to reduce the active material to soft sponge lead after exposure to the air.

The concentration of the electrolyte has a marked influence on the rapidity of self-discharge at the lead sponge element.

Dolezalek explains this by stating that on discharge, hydrogen is evolved around the impurities in the acid, and these play the part of hydrogen-electrodes and, therefore, with increase of acid concentration, have their voltages also raised and this voltage increase is extraordinarily great for variations in acid density, giving a corresponding increase in the ability to decompose the electrolyte and accelerate local action.

Differences of potential sufficiently great to effect decomposition of electrolyte, and therefore to produce local action, are sometimes caused by the difference in density of electrolyte in the top and bottom of a deep cell acting together with some other local E.M.F., which in itself would not be high enough to decompose the electrolyte.

The metallic impurities in the acid can cause no local discharge on the positive plate, unless they be such as are easily oxydized. These act as oxygen carriers from anode to cathode, and thus cause a transfer of charge which results in gradual internal discharge. All metals which occur in several degrees of oxydization have this property. For instance, iron salts become ferric salts at the anode, and travel to the cathode, where they deliver up their oxygen. They then return to the anode, receive a fresh supply of oxygen, go back to the cathodes, and so on continuously.

Manganese salts act in the same way, and are to be avoided in making up active material mixtures.

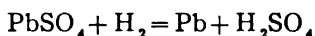
When the positive grid is fully covered with peroxide, there can be no local action between the active material and the grid, because a certain amount of lead sulphate is always present which fills the pores of the peroxide mass near the



bottom of the layer; *i. e.*, those pores lying nearest to the lead grid or plate and which are seldom acted on by either the electrolyte or the evolved gases of decomposition. The electrolyte, therefore, cannot penetrate completely through the peroxide and touch the leaden grid, and the conditions for local action are not fulfilled.

If, however, the peroxide should peel off or a cut be made through it, exposing the lead to the electrolyte, local action will take place, resulting in the production of lead sulphate which would form a protecting coating over the lead and stop the action.

If a battery in which local action has previously occurred between the peroxide active material and its grid, be short circuited or subjected to rapid discharge, the action again begins, because of the reduction of the protecting lead sulphate at the point of local discharge to sponge lead which will enter itself into the renewed action, and also permit the electrolyte to penetrate through it to the lead of the grid, and allow it also to take part in the destructive combination. This will continue as before, until the protecting sulphate is again formed. The change of the sulphate into sponge lead on the positive plate is due to an excess of hydrogen which is released at the positive plate on very rapid discharge—



If an element be repeatedly charged and discharged, and its capacity is found to reach a point at which it no longer changes, local action on the peroxide plate has ceased. If local action is taking place at this electrode the capacity of the element continuously increases.

When the capacity of a battery has reached a constant value, the amount of internal discharge due to local action may be determined by discharging the cell down to some point at which the remaining charge is of known value. Set the cell aside for a given number of days and then discharge the balance. The difference between the known value of the remaining charge and the amount actually measured, divided by the number of days which the cell was

put aside, will give a fair idea of the magnitude of the local action effect, provided the cell is carefully insulated and there is no external leakage.

The continuous increase of capacity on repeated charge and discharge in Planté plates is not to be always accepted as an indication that local action occurs, as the capacity of such plates increases up to about the fiftieth cycle of operation. Also, if the forming acid be not completely removed from the plates, formation will continue up to the point of destruction, the capacity meanwhile increasing with each charge and discharge. Therefore the foregoing is only applicable to elements which have been carefully formed and in which the lead dissolving acids used in formation have been completely removed.

## CHAPTER VIII.

### THE INFLUENCE OF TEMPERATURE.

The changes in ampere hour capacity, voltage on charge and discharge, internal resistance and efficiency with variation in temperature are surprisingly great. The change of electrolyte density with change of temperature has been previously discussed (Chapter V).

The effects of temperature changes have recently been investigated by Prof. Heim, of Hannover, and others, and

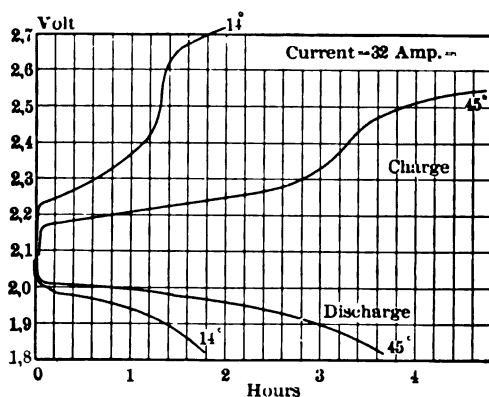


FIG. 13.

the experiments seem to have been carried out very completely and carefully. In Prof. Heim's experiments,\* the cells were fully charged up to point of copious gassing, the voltage readings at the cell being:

At 14° C.....	2.70 volts.
" 30° C.....	2.58 volts.
" 45° C.....	2.52 volts.

\*Elektrotechnische Zeitschrift, September 26, 1901.

These values show that the charging voltage decreases with a rise in temperature.

The contrary is true, however, on discharge, the voltage being higher with increase of temperature.

Fig. 13 shows the charge and discharge curves of a cell at  $14^{\circ}\text{C}$  and  $45^{\circ}\text{C}$ , which bring out clearly the differences in voltage mentioned. The current density was .109 amperes per square inch.

Prof. Heim also shows that the internal resistance of the cell changed with variation of temperature and his observa-

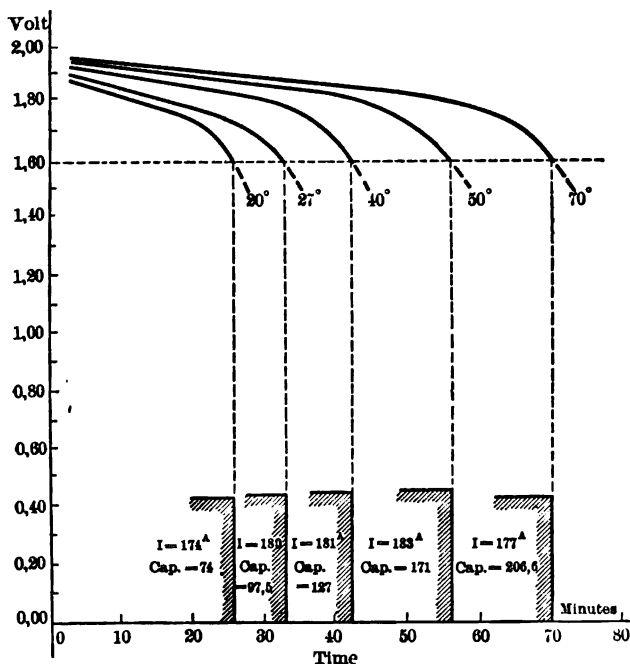


FIG. 14.

tions give the following results for a cell of three positive and four negative plates having a total positive plate area of 18.9 square decimeters; normal capacity, 69 ampere hours and acid density 1.22 at  $18^{\circ}\text{C}$ .

Internal resistance at  $14^{\circ}\text{C}$  = 0.0023 ohms.

" " "  $45^{\circ}\text{C}$  = 0.0015 "

This is a variation of .0008 ohms for 31 degrees, which is .0000258 ohms per degree.

At 0° C the internal resistance would therefore be  $.0023 + 14 (.0000258) = .0023 + .000362 = .002662$  ohms. Taking the

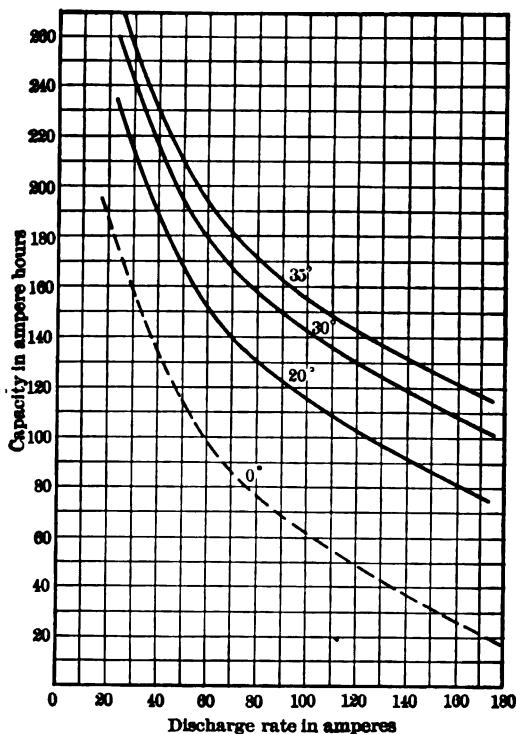


FIG. 15.

resistance at 0° C as unity, the decrease per degree C is .97 per cent.

Most marked, however, is the influence of temperature on the ampere hour capacity. Numerous tests on various sizes of cells show an increase which is practically of the same magnitude, but which does not seem to follow any general law.

Fig. 14 shows the variation in ampere hours at practically the same rates of discharge for a battery which is discharging

at a high rate. These curves show clearly that the percentage increase is not a constant, but varies with the position on the temperature scale. Fig. 15 is another set of curves showing the variation in capacity with temperature. From this it may be seen that the variation is greater the more rapid the discharge rate.

The following table gives the changes with temperature in the ampere hour capacity; ampere hour efficiency, electrolyte density changes, voltage and watt efficiency. The current density is given in amperes per square inch. Temperature in degrees centigrade.

TABLE V.

Temp.	CURRENT.		AMPERE HOURS.			AVERAGE VOLTS.				DENSITIES OF ELECTROLYTE AT 18°	
	Amps.	Dn'sty per Sq. In.	Charge.	Dis-charge.	Effi-ciency	Charge.	Dis-charge.	Volt Effi-ciency.	Watt Effi-ciency.	Charge	Dis-charge
14	20	.0685	76	71	93.5					1.241	1.215
14	32	.109	60.8	57.6	94.6	2.438	1.938	79.5	75.2	1.238	1.224
45	20	.0685	143	128	89.5					1.246	1.209
45	32	.109	128	108	85.0	2.326	1.953	84	71.3	1.246	1.219

This table shows that the ampere hour and watt efficiencies decrease with increase of temperature, though the volt efficiency increases with the temperature.

The electrolyte density was taken by removing a small quantity from the cell, bringing to 18° C and testing with a hydrometer.

A curious result of the change in capacity with heat, is the apparent ability by this means to get more current out of a cell than is put in on charge. In the tests referred to, a cell was charged at 14° C with 61.9 ampere hours at a rate of .109 amperes per square inch. The cell delivered on discharge after being heated to 45° C, 96 ampere hours. Charged at a rate of .0685 amperes per square inch, and temperature of 14° C, 76 ampere hours, were put into the

cell and it discharged 108.3 ampere hours on being heated to 45° C.

A further experiment on this line was the charging and discharging of the cell at 14° C and allowing it to stand one and one-half hours. After recuperation, it delivered 8 per cent. more current. Under similar treatment in every respect, except that the cell was heated to 45° C, while standing after the end of the first discharge, it delivered 33 per cent. more current after resting.

The explanation of these heat phenomena seems to lie in the increased porosity of the active material due to expansion under the action of heat, and the increased circulation of the electrolyte giving a more efficient use of the active material and the combining  $\text{SO}_2$ .

The fall of voltage on charge may be due to reduction of polarization E.M.F., by driving off the adherent and occluded gases. Possibly other causes may contribute to the decrease.

The capacity variations that will take place will depend for their absolute values on the thickness of the layer of active material, its character and its disposition, and the discharge rate.

It is evident that the more porous the active material at normal, and the lower the discharge rate, the less will be the increase in capacity for higher temperatures.

A rough, handy rule that somewhat approximates the degree of change in capacity with change in temperature, is:

At 6 hour rate, 1.5 per cent.					} per degree centigrade
" 3	"	"	2.5	"	
" 2	"	"	3.2	"	

the capacity at 15.5 degrees being taken as unity.

The influence of heat up to 45° C seems to be in nowise detrimental to the plates used in these experiments nor to increase their depreciation. Prof. Heim suggests that if in practice and after prolonged usage at high temperatures, it be demonstrated that within the limit of 45° C the durability is not impaired; it would be good commercial practice to provide means for warming battery rooms up to this point so that the increased capacity gained thereby may be made

useful in helping to carry abnormal loads that come on railway systems on holidays and at other times which occur so far apart that it would not be wise to invest in extra batteries or generating machinery to handle these loads.

It is, however, a well known fact that excessive temperatures are injurious to batteries and tend to decrease their life. The temperature of  $38^{\circ}\text{C}$ , seems to be about as high as batteries should be subjected to, according to the experience and statements of battery manufacturers.

A curious phenomenon first observed and investigated by Duncan & Wiegand in this country, and independently by

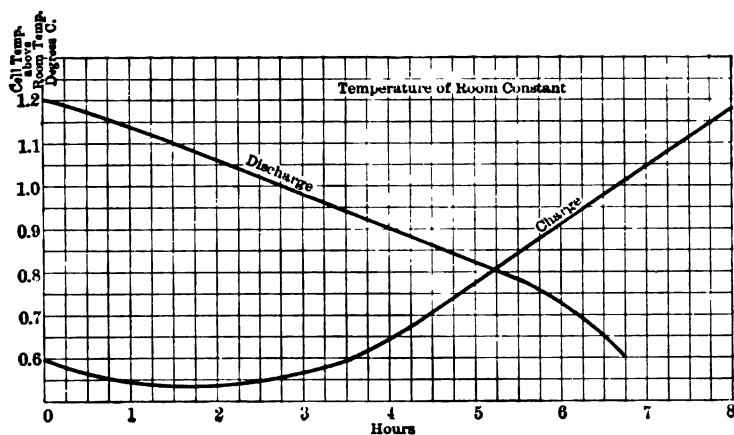


FIG. 16.

Prof. Ayrton, in England, is the decrease of temperature of a cell on discharge, though it may always be higher in temperature than the surrounding air. This decrease may be explained by the fact that sulphuric acid is abstracted from water on discharge and therefore the liquid cools; this being merely the converse of the well known fact that the addition of sulphuric acid and water is accompanied by the liberation of heat.

On charge the battery heats from two causes, one being the addition of  $\text{SO}_3$  to the liquid due to its electrolytic liberation from the  $\text{PbSO}_4$ .

The other factor is the  $I^2R$ , which, however, is not a con-



stant for any current as  $R$  varies widely. On discharge the abstraction of  $\text{SO}_2$  from the electrolyte tends to cool the battery; the  $I^2R$  to heat it.

The actual temperature change will be that due to the difference between these two factors and up or down, according to whichever predominates.

Fig. 16 shows curves of temperature on charge and discharge and indicates the rise and fall of temperature with time.

## CHAPTER IX.

### ON CAPACITY VARIATION.

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In a battery made up of a number of plates, each of a definite area, and carrying a given quantity of active material, the capacity in ampere hours will vary with several factors. These are

- (1) Character,
- (2) Porosity, and
- (3) Disposition of active material.
- (4) Quantity, and
- (5) Density of Electrolyte, and
- (6) Provision for its diffusion.
- (7) Temperature.
- (8) Rate of discharge.

The factors (1), (2) and (3) involve the matter of efficient use of active material. It is evident that with a given quantity of active material that the more porous it is made and the better it is disposed with reference to intimate contact with both the grid and electrolyte, the higher will be the capacity. Also (6) the more rapidly and thoroughly the electrolyte can penetrate to all parts of the material, the greater the discharge the battery will be capable of giving.

The effect of variation of (4) quantity of electrolyte on the capacity has already been discussed (Chapter VI) and it has been seen that the capacity increases somewhat with the quantity.

With reference to the density, it has been found experimentally that in the same cell, operated under the same conditions, the capacity increases with the concentration of the electrolyte up to about 1.225 and begins to drop off again from 1.260.

The fact that the resistance of the electrolyte is least at a density between these limits, would indicate that there would be less loss from internal resistance, and would doubtless partially account for the increase in capacity at densities between these limits.

It may here be noted that the capacity of a cell is also dependent on the number of discharges it has given. With Planté plates the capacity increases up to about the fiftieth discharge, after which it begins to slowly decrease, while with Faure plates the capacity increases up to about the fifth or sixth discharge, after which it begins to fall off.

The Planté plates continue to form and increase the amount of active material on the positive electrodes available up to about the fiftieth discharge, though the negatives lose capacity from the first discharge. After about the fiftieth discharge, the formation has practically reached its limit and the active material begins to shed. The re-formation does not quite compensate for the loss, and in the meantime the negative elements are beginning to lose capacity which effects combine to produce the slight, gradual decrease that continues to the end of the life of the battery.

In the Faure plates there is no available material from which peroxide can continue to form, and the first few charges and discharges merely complete the factory process of reduction resulting in maximum capacity. After the fifth or sixth cycle of operation, the gradual loosening of particles of active material, which turn into sulphate, and are not converted back into peroxide because they are not traversed by the current and which drop off from the grid, causes a small but continuous reduction in capacity.

The changes in capacity due to variations of (7) temperature have also been treated (Chapter VIII), and it has been shown that the capacity increases rapidly with increase of temperature.

(8) It follows from previous discussions, that the more rapid the discharge rate, the less will be the capacity of a given battery, the reasons for the decrease being failure of electrolyte to circulate as rapidly as required; masking of action by surface layer of sulphate; polarization, and in case

of very rapid discharge, formation of peroxide on the negative plate—all of which have been taken up in detail.

No accurate general rule can be given for the rate of capacity decrease, with rate of discharge increase, as the various causes effecting the decrease will vary in degree with different types of plates and also with different temperatures.

If the plates are of large active area, *i. e.*, finely subdivided,

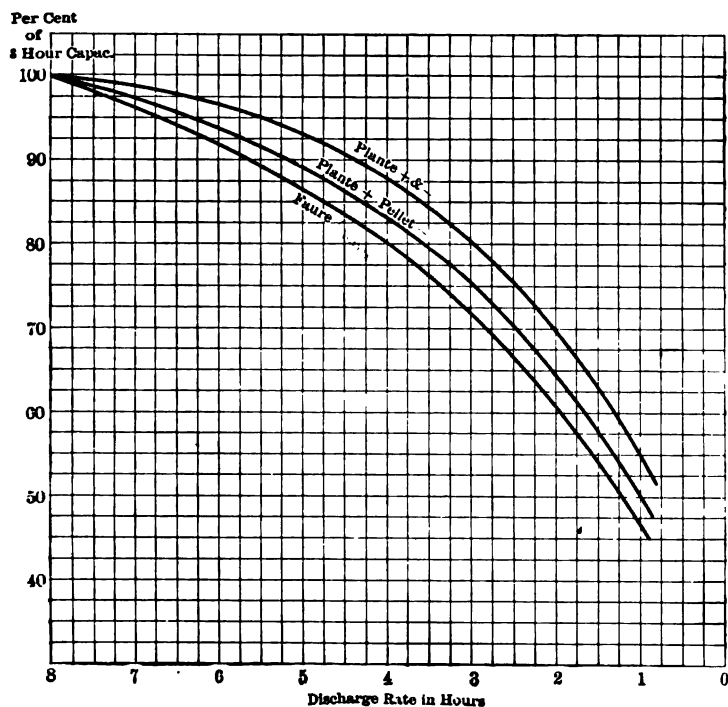


FIG. 17.

the layer of active material thin and porous, and the electrolyte ample in quantity and of proper density, so that the rapid formation of a surface of sulphate is prevented, it is obvious that the decrease in capacity will be less with high discharge rates than would be that of plates carrying the same quantity of active material in a thicker layer of less porosity and surrounded by a small quantity of electrolyte of high density.

Also, since the porosity and circulation of electrolyte are augmented at high temperatures, the decrease in capacity will not be so marked with warm batteries as with cold.

Though there is no practical law applicable to any type of cell, it is important that some rough general rule be formulated in order that the engineer may be able to intelligently design a plant to meet conditions of overload without battery exhaustion. The following tables give the variation in capacity with different discharge rates of three types of batteries, viz.: The Planté, positive and negative; the Planté positive and sponge lead pellet negative, and the Faure positive and negative.

PERCENTAGE OF CAPACITY VARIATION AT DIFFERENT DISCHARGE RATES.

RATE	% of Capacity at 8 hour rate.		
	Planté (1)	Planté pos. pellet neg. (2)	Faure (3)
8 hour	100	100	100
7 "	99	97	96
6 "	96½	93½	92
5 "	93	89	86½
4 "	88	83	80
3 "	80	75	72
2 "	70	65	61
1½ "	63	57½	53½
1 "	55	50	46

From these data are plotted the three curves shown here-with in Fig. 17. with the rates of discharge as the abscissæ and percentage of capacity as ordinates.

The table and curves show that as an average the percentages of the second type may be taken to use in making calculations of battery required to meet given conditions. Greater accuracy than this is not necessary, as the other variables, particularly temperature, make an exact calcula-

tion practically impossible. It is, however, advisable to secure from the manufacturer a set of discharge curves of his particular battery before laying out a plant.

From the table a series of factors "K" for the second type of cell, have been computed, and are herewith given:

TABLE OF FACTORS "K."

RATE.	K
8 .....	1.00
7 .....	1.03
6 .....	1.07
5 .....	1.13
4 .....	1.21
3 .....	1.33
2 .....	1.54
1½ .....	1.74
1 .....	2.00

The use of this table is to reduce the actual discharge at any given rate to an equivalent capacity at the 8 hour rate of discharge. The formula

$$I \times T \times K = A.H.$$

in which I is the discharge current; T the time this discharge continues; K the factor corresponding to I, and A.H. the equivalent capacity in ampere hours at the 8 hour rate; reduces any discharge to the unity basis on which most storage batteries are rated and sold.

Conversely, if the capacity of a battery at the 8 hour rate be known, its capacity at some more rapid rate is  $\frac{C}{K}$  in which C = rated capacity, and K = factor in table corresponding to the higher discharge rate.

These factors are principally of value in computing the capacity of battery required to discharge at varying rates for a given length of time, as shown in a subsequent chapter (Chapter XLIII).

## CHAPTER X.

### INTERNAL RESISTANCE.

The internal ohmic resistance of a cell when in a good condition, is usually very small.

As might be expected from considerations of dilution of acid in the pores and sulphatation on discharge, the ohmic resistance rises until at the end of discharge a maximum is reached which is from four to five times as great as the value

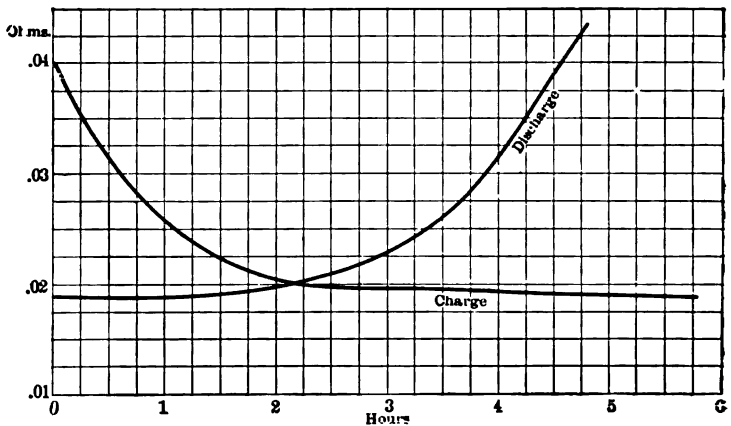


FIG. 18.

at the beginning of discharge; conversely the resistance decreases from beginning to end of charge.

It is practically constant for any current rate of charge or discharge, but varies as the amount of charge in the cell changes. The curves shown in Fig. 18 indicate the manner and degree of this variation. It is seen that the resistance drops on charge until a minimum is reached, after which the

change is almost inappreciable, the resistance becoming practically constant.

On discharge, the resistance begins to rise slowly, and then more rapidly as the discharge proceeds. The maximum resistance may be very high, depending on how far discharge is carried. If continued to the point of complete sulphatation of the plates, the resistance will be many ohms.

Methods for measuring internal resistance are given in the chapter on Testing.

The ohmic resistance is not the only cause, however, which is active in producing drop across the terminals of a cell when discharging or a rise when charging. Polarization effects, both of change in resistance and counter E.M.F., affect the drop to an important degree. The apparent resistance due to all these effects, the author terms "Virtual Resistance," and it is numerically equal to the difference between the voltage of charge, and that of discharge, divided by the sum of the current flows on charge and discharge. This is also equal to the difference between the voltage on open circuit and that on discharge, divided by the current flow. It is, of course, understood that the excessive rise when near gassing on charge, and the very great drop near the end of discharge, are not determining quantities in this connection. Both are terminal conditions, and though they must be taken care of when batteries are used on constant potential circuits, are not present in the general operation.

As will be seen later, certain coils on booster field windings are for the purpose of producing an E.M.F. in the armature, which just compensates for this drop across the battery. Hence it becomes important to settle on some value which can be used in these calculations.

The author has made a number of experiments on drop and internal resistance, and discovered that the drop in cells is practically a constant for any size or type, referred to a given time rate of charge or discharge, and a given state of battery charge.

The following table and the curve shown in Fig. 19 show how the drop is related to the rate of discharge and is independent of the size or type of cell. This latter is, of course,



not strictly true, but is nearly enough so for all practical purposes. Accuracy requires a test of the particular battery or type on which information is desired, but for usual engineering calculations this table and curve given herewith are sufficient. Figures are for battery *one-third discharged*.

TABLE VI.

	hour rate.....	DROP. volts.
8	hour rate.....	.05
6	" ".....	.065
4	" ".....	.09
3	" ".....	.11
2	" ".....	.14
1½	" ".....	.185
1	" ".....	.21

These values are for a continuous discharge of two minutes or more at the rates mentioned. Usually, however, the

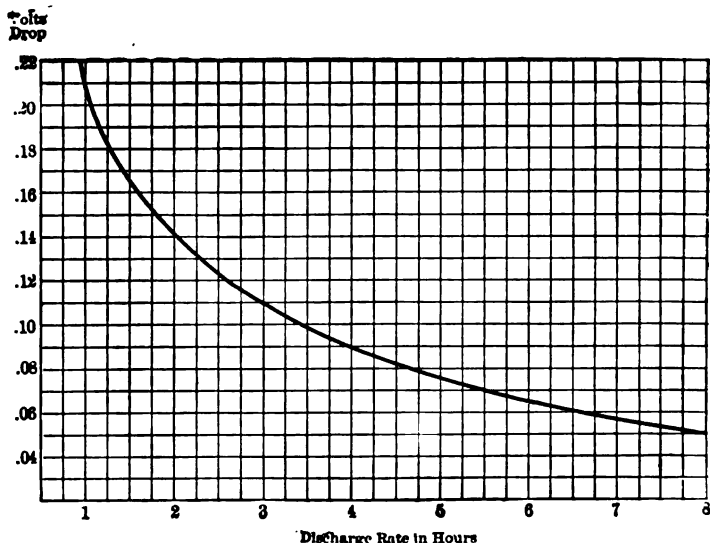


FIG. 19.

duration of the maximum rates is only momentary and the values reached on the 1, 1½ and 2 hour rates will not be over 70 or 80 per cent. of the figures given in the table.

In the booster formulæ mentioned, the factor referring to compensation for drop or rise across the battery, appears as the internal resistance of the cell, and it is necessary to put the data in this form, which may be done by the following formula:

$$R = \frac{.09}{D} \dots\dots\dots (9)$$

In which

R = virtual internal resistance of cell.

D = 4 hour discharge rate.

Any value of drop given in the table, may be used if it be divided by the current corresponding to the rate to which it appertains. Thus, in a cell with a 4 hour rate of 100 amperes, the virtual internal resistance would be

$$\frac{.09}{100} = .0009 \text{ ohm.}$$

This drop will also vary with temperature, condition of cell and electrolyte density, and the figures given are *only averages*.

It must be remembered that in case of a number of cells, joined in series, the ohmic resistance of the connectors and leads to the booster—including switch contacts and other joints—must be added to the virtual internal resistance to obtain the ohmic resistance of the battery circuit.

## CHAPTER XI.

### EFFICIENCY.

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The efficiency of a battery is the ratio of the useful current or energy given out on discharge to that put into it on charge. The ampere hour efficiency is the useful discharge in ampere hours, divided by the number of ampere hours input on charge, and the watt hour efficiency is the ratio of watt hours output to watt hours input. It is usually customary to state the efficiency in ampere hours, though the reason for this does not appear, as ampere hour efficiency does not convey any definite idea of the energy efficiency.

The work absorbed or given out by a battery is measured in watts, and only the energy or watt efficiency is of value to the engineer. The ampere hour efficiency is always high, and its usage no doubt results from the attractive figures which manufacturers are able to present in discussing battery efficiency for the instruction of prospective purchasers.

The efficiency of a battery depends on

- (1) The charging rate.
- (2) The discharge rate.
- (3) The internal virtual resistance.
- (4) Thickness and porosity of layer of active material.
- (5) Density, quantity and diffusion of electrolyte.
- (6) Length of time elapsing between end of discharge and beginning of next charge.
- (7) Freedom from local action.
- (8) Temperature.

In charging, energy is lost in the evolution of gases; in heat—true  $C^2R$  loss—and counter E.M.F. of polarization, and in an amount which is somewhat proportional to the rate of charge.

On discharge, energy is lost in heat and polarization,

counter E.M.F. and these losses also increase with the discharge rate.

It has been shown that the lower the rates of charge and discharge, the nearer the voltage curves approach together, and as the difference between these two represents the pressure loss, it is obvious that the efficiency is higher at low rates of charge and discharge than at rapid rates. The internal ohmic resistance and the virtual resistance tend to increase the voltage of charge and decrease that of discharge, causing a loss of energy. The efficiency is therefore largely dependent on the internal resistance, though it is influenced also by certain chemical effects, especially gassing.

The thickness and porosity of the active material influence the values of the internal resistance and consequently the efficiency. Where the charging rate is rapid, the layer of active material thick and diffusion imperfect, the voltage of the cell rapidly rises because of the high concentration of acid in the pores, which is unable to diffuse out into the surrounding electrolyte. This requires a higher charging voltage and the energy input is increased beyond the amount of actual energy stored. This lost energy appears as heat, and it will be found that batteries subjected to a high charging rate always heat up to a temperature above that due to mere internal resistance. The physical conception of the cause of the heat is the rapid addition of  $\text{SO}_3$  to  $\text{H}_2\text{O}$ , which always form a chemical mixture liberating heat.

Certain secondary chemical reactions may also tend to increase the cell E.M.F. on charge and lower the efficiency. Prof. George Forbes has termed the excess voltage above the normal 2 volts "spurious" E.M.F., and calls attention to the great increase in efficiency that might be attained if this spurious E.M.F. could be eliminated. He mentions a test made on one of Fitz-Gerald's lithanode cells, in which this spurious E.M.F. did not exist and which showed extraordinarily high efficiency. No explanation has been given of the reason why this particular cell happened to be free from a defect that is universal, further than that the grid on which the active material was pasted was celluloid.

On rapid discharge polarization is increased, and assists in

reducing the battery voltage. Also the extreme dilution of the acid in the pores of the plates—the converse of the effect noted on rapid charge—causes the E.M.F. to fall rapidly, and assists to end the discharge more quickly. As an example of variation in efficiency, with charge and discharge rates, the following results of a test by Dr. Franz Peters\* are given:

CHARGING RATE.		DISCHARGE RATE.		Amp. hr. effic. %
amps.	amps. pr. sq. in.	amps.	amps. pr. sq. in.	
10	.121	9	.109	95.7
10	.121	6	.073	98.7
16	.1935	9	.109	80.8
16	.1935	6	.073	83.2

Unfortunately the watt hour efficiencies are not given, but these would show a far greater difference between moderate and rapid current rates than the above figures.

It is not to be supposed, however, that if a battery be charged and afterwards discharged at a rapid rate, the ratio of output to input is the true efficiency. Whenever the output is far less than the input just preceding, it will be found that the succeeding charge will be less than the previous one. Also the recuperative capacity of the battery is much greater than if the discharge had been normal. In other words, if a battery be discharged at a rapid rate, the available energy is not taken out of the cell by the time the voltage falls to 1.8, and there is a considerable residual charge left. Failure to appreciate this fact has frequently led to erroneous determination of battery efficiencies. Efficiencies should be calculated as the summation of a series of cycles of charge and discharge, all being at the same rate and under the same conditions.

If a cell which has been rapidly discharged, be allowed to stand for a considerable time, the residual charge will be partly lost by the absorption of some hydrogen, and the in-

\*Centralblatt für Accumulatoren, Jan. 15th, 1901.

effective combination of the  $\text{PbO}$  with the  $\text{SO}_2$ . Therefore the efficiency is higher if the charge and discharge succeed each other rapidly. This is the condition under which regulating batteries operate which equalize fluctuating loads. They also have the advantage of charging and discharging at a point where the charging voltage is below the gassing point, and the discharge E.M.F. is near its highest.

If current be alternately taken out of and put into the cell at short intervals, the *quantity* of charge will not be materially altered even though the *rate* may be rapid, because the *time* of charge or discharge is short. Therefore

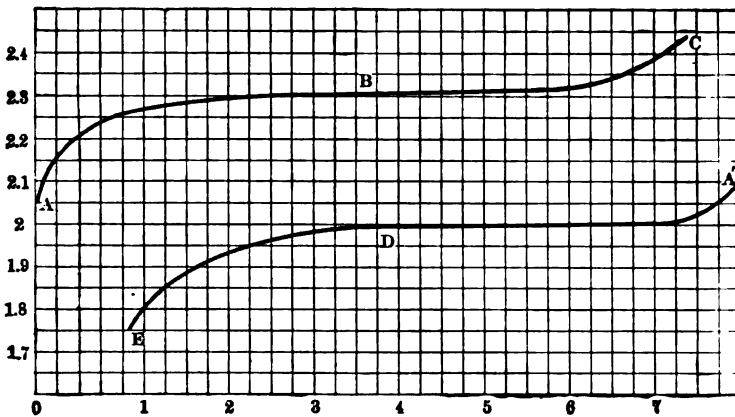


FIG. 20.

the point on the voltage curves of charge and discharge at which current is put into or drawn from the battery, will shift but little.

Consider the curves shown in Fig. 20. A.B.C. is the curve of charge and A.D.E. that of discharge, the latter being plotted backwards with reference to the abscissæ. If the average charge in the battery be such that charge and discharge take place around the points B and D, respectively, there will be but a small voltage loss as the curves are not so widely separated at these points as at points nearer to complete charge or discharge.

The investigations of B. Hopkinson\* on the subject of efficiency of "floating" batteries, show that the watt efficiencies are much higher than is the case with cells used for storage. The longer the duration of charge or discharge, the less is the efficiency. Cycles of one minute—one-half minute charge and one-half discharge—show from 90 per cent. to 97 per cent., and cycles of ten minutes from 87 per cent. to 93 per cent. In these experiments the cells were worked at points on the curve where there was no gassing on charge. This is also the usual condition in practice, and the above results have a practical value.

It may be mentioned here that batteries other than lead cells, and which have a low E.M.F., say from .75 to 1.3 volts, can never have a very high efficiency, however well they may perform their work. The reason lies in the fact that the lower the voltage of a cell, the greater is the ratio of internal resistance and polarization drop to the cell E.M.F., and, consequently, the drop is a large proportion of the total cell voltage. Therefore, while such batteries may be excellent for conditions where current cost is a secondary consideration—such as motor car work—they would hardly pay dividends in a central station where a difference of two per cent. in efficiency is often the determining factor in the selection of any apparatus.

The density, quantity and diffusion of the electrolyte all have a marked effect on the efficiency of a cell. The density must be such that the resistance of the electrolyte is low; the quantity must be sufficient to prevent a great change in density on discharge, and the voltage is largely dependent on the ratio of diffusion.

If the diffusion is poor, the electrolyte in the pores of the plates will be subject to great concentration on charge and dilution on discharge, with a correspondingly augmented voltage in the one case, and diminished in the other. Therefore, if the quantity, density and rate of diffusion of electrolyte are of proper value, the result will be a low voltage on charge (up to the point of gassing) and a high voltage on

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\*"Losses of Energy in Accumulators." London *Electrician*, Nov. 29th and Dec. 6th, 1901.

discharge, and if a cell be deficient in these particulars the increase of the one and the lowering of the other will cause a loss of energy and a decrease of efficiency.

If a cell be allowed to stand discharged, sulphatation proceeds, and on subsequent charge a greater number of ampere hours at a higher voltage must be put into the cell to bring it up to full charge than would be required if the charge had been begun immediately after ending the discharge. The excess energy necessary to fully charge the cell represents a corresponding loss in efficiency. If internal discharge takes place, the amount of energy so used up is lost, as it does no useful work, and therefore the efficiency is decreased.

It has been previously shown that the efficiency of a battery is less at high than at low temperatures.

Under usual conditions, the watt efficiency of a battery used for storage only, is from 70 to 80 per cent. The larger the battery, and the higher the voltage at the end of discharge, the greater will be the efficiency. With large batteries in which the charge is never continued very long after gassing begins and discharge is stopped at about 1.87, the efficiency of storage cells may be as high as 85 per cent. A fair commercial figure is 80 per cent. for storage, and 92 per cent. for regulation batteries.

Methods for determining efficiency are given in the chapter on Testing.



## CHAPTER XII.

### DURABILITY AND CAUSES OF DETERIORATION.

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The durability of a battery is dependent on

- (1) The character of the active material.
  - (2) The adhesiveness to the support.
  - (3) Means by which active material is held in position (Faure plates).
  - (4) Thickness of layer.
  - (5) Porosity.
  - (6) Distribution over the surface of the support plate.
  - (7) Density
  - (8) Quantity
  - (9) Purity
- } of electrolyte.
- (10) Rate of charge per unit of plate area.
  - (11) Rate of discharge per unit of plate area.
  - (12) Duration of maximum rates.
  - (13) Maximum voltage to which cells are allowed to charge.
  - (14) Minimum voltage to which cells are allowed to discharge.
  - (15) Time elapsing between the cycles of charge and discharge.
  - (16) Maximum temperature at which cells are operated.
  - (17) Maximum length of time cells are permitted to stand idle in electrolyte.
  - (18) Efficiency of separation between plates.
  - (19) Freedom from conditions favorable to local action.
  - (20) Location with reference to gases which might be absorbed in the electrolyte and prove injurious to the plates.

- (21) Amount of available base lead on the peroxide elements which may be converted into active material (in Planté plates).

In previous discussions, most of the characteristics enumerated and their effects on the general working of batteries, have been considered. This chapter, therefore, is practically a recapitulation of preceding observations, collated with reference to their effect on the life of a cell.

(1) The character of the active material which is best suited to produce long life, is hard and tough, yet porous and of low specific gravity. The coherence between the particles should be of a high order, and the whole should be a strong, compacted mass, hard like soapstone, in the case of the peroxide element, resisting the thumb nail, while the spongy lead element should be soft and easily pressed into by the nail. Such materials can expand and contract without shedding or dropping particles from its surface.

(2) The material must also be firmly attached to the support plate or grid. Otherwise parts may peel off, no matter how coherent the active material itself may be. Poor contact, also, allows gradual sulphatation of active material, as it is not thoroughly traversed by the charging current and changed back to its proper state,  $Pb$  or  $PbO_2$ . Furthermore, there is always the possibility of a layer of sulphate forming between the grid and the active material—this latter applying more to the Faure than to the Planté type of plate.

(3) The efficiency of the envelope in batteries made with pasted plates affects the durability, as is obvious.

(4) The thickness of the layer of active material is also a factor and depends on the service the battery is to perform. Since expansion occurs on discharge and contraction on charge, there is always a tendency to break off the active material or to distort the plate itself if this expansion be too great. Therefore, the thicker the layer, the less the area will be for a given quantity of active material and the less the expansion. If, however, the layer be too thick, the capacity is lowered and other considerations, previously given, require, in most instances where the battery is to

charge or discharge at rapid rates, that the layer be thin. Only in batteries that operate under moderate rates of current flow, should the layer be thick.

(5) The greater the porosity, the more accessible is each particle of active material to the electrolyte, and the more complete and uniform the chemical action; also the expansion tending to distort the plate will be less, as the pores leave some space which allows the molecules to increase their volumes: in other words, the material becomes more dense on discharge.

(6) The distribution of the active material over the support plate has a most important bearing, in that, unequal distribution or unequal densities or unequal closeness of contact with the grid at different points on the surface will result in unequal distribution of current. This causes unequal expansion of the different parts of the same plate and allows some of the active material to become overcharged from excess of current flow through it while other parts are undercharged. The charge tends to equalize itself over all the active material after the battery has stood for a short time with current cut off, but before this equalizing takes place, and during it, conditions are favorable for local action.

(7) If the density of the electrolyte be too high, there is danger of sulphatation. Also, if the tanks be of much depth, there is a greater tendency for the densities at the top and bottom to vary widely than is the case with lower density of electrolyte. The difference of E.M.F. caused by this difference in density, is generally sufficient to cause nearly all of the electrolytic action to take place on the lower portions of the plates. If tanks exceed 20 inches in depth—which should be the maximum allowable depth—the lower ends of the plates will soon disintegrate and renewals required, though the upper portions of the plates may be perfectly good.

(8) If there is not enough electrolyte in the cell, the density toward the end of discharge—especially in the pores of the plates—becomes low and the acid is highly diluted. The electrolytic decomposition of highly dilute solutions

has a different effect on the plates from that of denser solutions and has a deleterious corrosive effect, which shortens the life of the elements.

Duncan and Wiegand mention that they observed a change in the chemical action on lead plates, when the dilution of the electrolyte had reached a certain point and a different compound from peroxide of lead was formed, with the result that the plates were rapidly eaten away.

(9) The effects of impurities in electrolyte are generally to corrode and eventually disintegrate the plates, to fill up the pores and decrease their capacity, or to cause local action by deposition on the plates and producing with the active material on which it may be deposited, a couple which causes local action.

(10) If the rate of charge be moderate, the concentration of the acid in the pores and other chemical actions take place within moderate limits, and the contraction also is less harmful as it is not rapid, and the active material has time to gradually accommodate itself to the changing conditions. From this it may be seen that the higher the maximum rate of charge, the more deleterious it may be to the plates. Also if there be much sulphate present the battery will heat with rapid rates of charge. If the rate of charge be too low—as small as one-thirtieth of the normal rate—sulphatation will result.

(11) Moderate rates of discharge are desirable just as moderate rates of charge are, and for practically the same reasons. Rapid charge is more harmful, however, than rapid discharge, owing to the fact that the material in the former case is contracting and may, if too rapid, pull loose from the grid.

Rapid discharge may also produce peroxide on the negative plate by reason of the copious release of oxygen, and other products of electrolysis. The final result would be local action. Also the observations of Duncan and Wiegand with reference to the changed character of the products of electrolysis in weak acid solutions may offer some explanation of the reason for deterioration of a battery when the discharge rate is very rapid. The electrolyte

in the pores of the plate quickly loses its acid and becomes highly diluted, which may lead to the more rapid depreciation than is observed on slower rates of discharge.

(12) From 10 and 11 it follows that the bad effects due to high current rates are proportional to the times during which they continue.

(13) While it is occasionally advisable—say once a month—to charge the batteries up to about 2.65 volts per cell, this would be harmful if done continuously, because the gases formed inside the pores are liable to crack or peel off the active material in forcing their way out. They also may force themselves between the active material and the grid, thus decreasing the contact between the two and paving the way for troubles from sulphatation by secondary action.

The active material is also liable to break or “shed,” because its volume changes greatly owing to the complete reduction of sulphate. It is, however, well to overcharge several times each year in order to completely convert the sulphate which may have accumulated, into peroxide.

(14) The minimum voltage to which a battery is permitted to discharge is probably the most important of all the factors which affect durability. If the discharge be carried too far, over sulphatation, dangerously great change in volume of active material, resulting in fracture, shedding or buckling, excessive dilution of acid in pores, resulting in corrosive electrolytic action, are the possible consequences.

(15) Time elapsing between discharge and charge. If considerable time elapses between the end of discharge and the beginning of charge, sulphatation invariably occurs. Cells which are fully charged, and which are allowed to stand idle for any considerable length of time will discharge themselves by leakage and local action, and the active material gradually becomes sulphated.

The sooner a battery can be charged after the end of discharge, the more satisfactory will be its operation and the longer its life.

(16) The maximum temperature at which a battery

is operated should not exceed 90° F., and certainly not be greater than 100°. At high temperature the chemical activity is more rapid, the pores more open, and tendency for sulphatation therefore greater than at lower temperatures.

(17) If the plates are not efficiently separated, and leakage or short circuits can form from one plate to the one adjacent, obviously the conditions for internal discharge and ultimate sulphatation, will be present.

(18) If batteries be located where fumes or gases which carry lead attacking elements, may be absorbed by the electrolyte and afterwards travel from the anode to cathode, and back again, as charge and discharge take place, the probability is that the plates will finally be disintegrated. This is a condition which might easily obtain in a chemical works, and there are authentic instances of batteries which were installed in ammonia refrigerating plants, quickly going to pieces, due to the absorption of ammonia by the electrolyte and its conversion into nitric acid by action of the current.

(19) In Planté plates the life of the positive elements is dependent largely on the amount of lead in the plate, available for conversion into active material. As the peroxide coating sheds, the action of the charging current converts the exposed lead left, into peroxide, and in this way the plate is being continuously re-vitalized. The usefulness of the plate is ended when the available lead is completely used up.

Usually the positive plates next to the outside negatives disintegrate before the other positives show signs of serious depreciation, because they are more active and give more than their proportional amount of current on discharge. This is due to the fact that the current flow from the outside negatives is less than from the other negatives because only one side is active. The drop, therefore, is less, and in the tendency to equalize the drop between different plates the outer negatives supply more current than they should, and cause an excess of current flow in the adjacent positive plates.

## CHAPTER XIII.

### DISEASES AND THEIR REMEDIES.

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From the enumeration of conditions for durability, it can be seen that the most troubles are the results of failure to observe the requirements cited.

The principal diseases to which a battery is subject are:

- (1) Loss of capacity.
- (2) Corrosion of plates.
- (3) Fracture and buckling.
- (4) Shedding of active material.
- (5) Sulphatation.
- (6) Reversal of negative plates.
- (7) Internal discharge.
- (8) Hardening of negatives in air.
- (9) Loss of voltage.

(1) Loss of capacity—as distinguished from loss of charge—may arise from (a) clogging of pores of the lead sponge with sulphate or impurities; (b) contraction of the pores of the mass; (c) loss of active material from the grid; (d) formation of a layer of sulphate between the grid and the active material; (e) loss of electrolyte.

When the negative plate shows a decreased capacity, and exhibits no sign of sulphatation, nor loss of material, it will generally be found that the material has shrunk or the pores are clogged with sulphate and impurities.

The rejuvenation of these plates is accomplished by discharging the battery, removing the negative elements, placing them in a bath of 1.200 density sulphuric acid, and connecting them as anodes or in a reverse manner to that in which they are normally connected. As cathodes, "dummy" plates of plain sheet lead about one-sixteenth inch thick are used. On passing current through the plates,

the sponge lead turns first into  $\text{PbO}$ , then  $\text{PbO}_2$ , as the action continues. When the sponge lead becomes completely peroxylized, the current is again reversed, the acid in the bath first being removed and fresh acid substituted in order that the impurities may not be redeposited on the negative plates. When the elements are finally converted back into sponge lead and reassembled with the positives, it will be found that the capacity and activity of the battery are increased and brought up to nearly their original condition. Reversal of the complete battery—both positives and negatives—should be avoided if dummies can possibly be secured. If not, however, and the reversing be carefully done, possibly no harm will result to the positive plates.

The rate of current flow on reversal and the subsequent change back to sponge lead, should be about one-half of the eight hour rate, say, as a general rule, .025 amperes per square inch, or three and a half to four amperes per square foot of positive plate ( $= \text{N}^\circ \text{ of } + \text{ plates} \times (\text{length}) \times (\text{width}) \times 2$ ). The acid in which the change from sponge lead to peroxide takes place, should not be used as electrolyte until the impurities discharged by the plates are removed.

Loss of electrolyte by leakage, evaporation or otherwise, should be made up by proper addition of highly dilute acid—about 5 per cent. acid to 95 per cent. water. If the liquid does not completely cover the plates a smaller active mass is exposed, and the capacity proportionally decreased.

(2) Corrosion of plates may occur from two causes: (a) the chemical action resulting from electrolytic decomposition of highly dilute acid in the pores of the active material, and (b) the presence of lead dissolving acids or their salts in the electrolyte.

The first condition cannot be remedied, as it occurs in every cell if the discharge be pushed too far, or if the plates have a thick layer of active material when the rate of discharge is high. If the electrolyte contains lead dissolving acids, their presence will be manifested by a continuous increase of capacity, which means that the forming process still goes on attacking the plates. The obvious remedy is to change the electrolyte, and substitute fresh acid free from



injurious substances. In addition to these effects, there is the normal slow disintegration due to the action of the acid and products of decomposition, which cannot be completely stopped, as it is the natural depreciation to which plates are subject. It can be partly remedied, however, by decreasing the density of the electrolyte.

All corrosive actions of liquids on solid substances immersed in them take place with greatest rapidity at the surface of the liquid, and battery plates which project above the electrolyte go to pieces at its surface before the submerged portions have greatly depreciated. This can be rendered of small importance by keeping the plates always completely covered with liquid, and making the lugs which pass from the plates out to the terminals of thick, dense lead.

(3) Fracture and buckling are due to excessive or unequal expansion; usually the latter. They indicate that the discharge has been carried too far, the rate too rapid, or that the current distribution over the plate was not uniform, and certain portions were too far or too rapidly discharged. It will be seen that buckling can take place even at normal current rates if the formation of active material or its application, be not uniform over the exposed surface. Should buckling occur under these conditions, it would indicate a defective plate.

Buckling on rapid rates of discharge may be due to slight inequality of distribution of active material, together with differences in electrolyte densities which occur in deep tanks. Batteries which are discharged at a high temperature may also buckle, due to the increased capacity and consequent additional formation of sulphate, thereby changing the bulk of the active material more greatly than if the discharge had taken place at a lower temperature, and less capacity had been delivered.

A phenomenon observed by Sir David Salomans and yet unexplained, is the buckling of plates exposed to light, the convex side always being away from the light.

If the troubles arise from defective plates, there is no remedy save to keep the electrolyte circulating, refrain from discharging too far, and keep excluded from light and heat.

(4) Shedding of active material cannot be prevented if it be improperly formed or applied, and is of such a character that it easily disintegrates or loosens from the grid. Shedding occurs with good active material, however, to a limited extent, and this is due to expansion and contraction, which the grid cannot follow, or to the rapid release of gases when charging is done at high rates, or the plates are over-charged. When shedding takes place in a greater degree than ordinary usage and depreciation call for, the following rules should be observed:

Charge at lower rates; do not overcharge, *i. e.*, do not go above 2.4 volts; do not discharge down too far, say below 1.8 volts, and, if possible and not originally done at the factory, cover the plates with an envelope of some kind.

(5) Sulphatation of the injurious kind differs from the normal sulphatation of charge and discharge, in that it is almost irreducible, causes shedding of active material, buckling, loss of capacity, increase of internal resistance with consequent reduction of efficiency, and increase of temperature with passage of current.

Many investigators maintain that the injurious sulphate differs from the useful sulphate in character and chemical composition. Others have decided that there are not two sulphates, but that the injurious sulphate is the same as the useful, the difference being in the degree of reduction. Pure lead sulphate having a low conductivity, being in fact almost an insulator, cannot be reduced or oxydized, because current cannot be made to traverse it. If, however, it be mixed with a sufficient quantity of lead or lead peroxide to give the mixture porosity so that electrolyte may be absorbed and produce conductivity, the normal action of charge and discharge can take place. This latter theory appears the rational and proper one, and many experiments seem to confirm it. The injurious sulphatation, then, is simply over-sulphatation.

The causes of over-sulphatation are over-discharge or rapid discharge, either of the entire mass of active material or only certain portions of it, and the injurious effects are those which arise from great increase in resistance and ex-

cessive expansion and contraction, which are mentioned above.

The causes of over-discharge are: (a) intentional, through external circuit; (b) local action and leakage; (c) loosening of active material which discharges but is not traversed by current on charge and consequently becomes over discharged; (d) short circuits between plates.

Excessive discharge rates also tend to form a surface layer of sulphate, which prevents the inner portions of the active mass from participating in discharge and thereby causes the action to take place on the small portion forming the outer layer which results in over-discharge of the surface and formation of the non-reducible sulphate.

When the active material is not in close contact with the grid, and the electrolyte is able to penetrate between the two, it is evident that on discharge the action will take place most rapidly on that portion of the active material nearest to the grid, and a layer of sulphate will be formed on this surface. When the sponge lead or peroxide are sufficiently reduced, the layer of sulphate between the grid and the active mass becomes non-conducting, and current cannot be forced through the plates, except at a high voltage. If the acid density or the temperature be high the process of sulphatation is augmented.

In addition to these injurious effects, those previously mentioned, due to change of the volume of the active material are usually present. Cracking and shedding of active material, and buckling, generally result.

Local action will cause over-discharge and consequent sulphatation, as will also short circuit between the positive and negative elements.

As sulphate is white, the manifestation of its presence is through the gradual lightening in color of the sulphated parts. If the process continues, eventually flakes of white, pure sulphate will form over the plates or the portions that are affected. The best treatment for sulphated plates is a matter of opinion. Many workers claim that the best results are obtained by charging at a low rate—about one-fourth normal—for a long time, and by this method the

sulphate is gradually reduced. Others are of the opinion that high current densities are more suitable. The author has found, in his own experience, that if the sulphatation has proceeded very far, the heating of the cells due to high resistance, limits the rate of the current flow, and he believes that the charging rate should be determined by the thermometer, and should be as high as possible with the temperature not to exceed 105° F. Usually at the beginning of charge the current which will produce this temperature is very small, and rapid initial rates are not possible, though the current can be increased as the reduction proceeds.

Plates which have a layer of sulphate between the grid and the active material are usually not reducible and must be renewed and replaced by others. Sometimes, however, if the layer is not too thick or completely turned to sulphate, the reduction may be effected. If the sulphating action has gone so far that the white flakes are formed, the plates should be taken apart and the positives and negatives separately connected up with dummies, and current passed through in the proper direction (positives as anodes; negatives as cathodes) to reduce the sulphate. If sulphatation is produced by local action, the causes thereof should be investigated and removed (Chapter VII).

The density of electrolyte and temperature should also be within the prescribed limits. While neither of these factors causes sulphatation, they greatly assist the real causes and accelerate and augment this injurious action.

Short circuits should be prevented by keeping the cells cleaned out and never allowing the sediment—which is a conductor—to accumulate in the bottom or between the plates on the separators. Also, the separators and spacing of the plates should be given occasional attention.

When an excess of sulphate once forms, several cycles of charge and discharge are necessary to bring up the battery to its normal capacity. The first charge should always be a prolonged over-charge. When large cells are connected up in series, as is usual, and it becomes necessary to charge a single cell sufficiently to bring it up to proper condition without subjecting all the other cells to an injurious over-

charge, it is usually done by cutting out the defective cell and arranging short lengths of wire or cable—called “jumpers”—so that the cell may be connected in circuit with the others on charge, and cut out on discharge, the current being passed around the defective cells by means of a “jumper.” A repetition of this process will finally produce the desired over-charge.

If the cell has to be brought up to condition quickly, it may be connected in with the others on charge in the regular way, and in a reverse direction on discharge, so that the discharging current of the system passes through the defective cell as charging current. The process is in this way continuous, but it is awkward to handle the large “jumpers” and contacts that are required for large cells, and the application is therefore limited to the smaller sizes of cells. Furthermore, the cutting out of a cell decreases the voltage of the system two volts, and if it be cut in on discharge in a reverse direction the drop through it will be about 2.5 volts, making 4.5 volts lower e.m.f. on the system. The service, therefore, must be such as to admit of this drop, or the end cells or booster must be able to compensate for it.

(6) Reversal of negative plates occurs only when there are several cells in series, with each other, or some external e.m.f. and is occasioned by complete discharge down to zero and continued charge in a reverse direction with a consequent reversal of the plates. This seldom happens, however, except in cases where a cell loses its capacity through some accident or defect, and its discharge is ended before the other batteries in series with it have begun to come down. The large capacity cells overpower the defective cell and reverse it. The remedy, of course, is to recharge and to continue the charge until the cell is brought fully up to its normal condition. The cause of the capacity loss should be ascertained and corrected, otherwise the reversal will occur on the next discharge.

To over-charge a battery in series with other cells, the usual method of connecting in on charge and cutting out on discharge, as mentioned in the paragraph on sulphatation, is advisable.

(7) Internal discharge has been fully treated in the chapter under that caption. The remedy is to use pure electrolyte and keep the plates well covered. Local action often results in filling up the pores of the lead sponge with deposited impurities and sulphate, thereby reducing the capacity.

If the negatives are of such character as to stand reversal they may be revitalized by this method, as described in the early part of this chapter, under the heading "Loss of Capacity."

(8) Hardening of negatives in air which proceeds from oxydization, occlusion and heating, leaves the sponge lead in a condition difficult to reduce to its proper form. The only way is by a continued over-charge, and, if possible, this should be done against "dummy" positives, as the battery positives would probably be injured if subjected to the amount of overcharge that is necessary to remedy this condition. Generally, the safest way to handle negative plates that have become hardened by exposure to the air, is to send them back to the factory and have the suppliers furnish new ones, or carry out the reduction of the defective ones. If, however, the conditions are such as to require immediate use of the battery, and no "dummy" positives are available, the over-charging may be done at a low rate—say one-half normal—without probable serious injury.

(9) Loss of voltage. This is of frequent occurrence. Generally, in a battery, one or more cells show a lower voltage than the normal, and at times may even reverse their polarity. This diminished E.M.F. is due to an abnormal amount of sulphate in the active material which must be reduced and the cause of its formation removed, as explained in the paragraph on sulphatation.

## CHAPTER XIV.

### CARE AND MANAGEMENT.

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In addition to the foregoing discussions, there are a few points concerning the operation of batteries which should be noted.

The one hour rate of discharge should never be exceeded, and this should last only a short time, say twenty minutes, except in the case of regulation batteries, where the forty-five minute rate may be allowed for a minute or two when the load fluctuations are very great.

The rate of charge may be rapid when the battery is nearly or quite exhausted, but should be low when nearing the end of charge, that is, after the evolution of gas begins. A good rule for rapid charging is 35 per cent. of total the first hour; 52 per cent. the next two hours, and 13 per cent. the fourth hour. Never charge at too low a rate, as it is injurious. The 30-hour rate should be a minimum.

Take occasional voltage and cadmium readings of each cell to keep informed as to the performance of the separate cells and plates. Also test each cell with a hydrometer at least once each week. Acid density lower than that of other cells will generally indicate local action or short circuit.

The hydrometer used for measuring acid densities should be as large as possible to use conveniently, and with not too great a range, otherwise the scale will be too short and the divisions too close together to obtain accurate readings. In small hydrometers the error introduced by the meniscus that forms around the stem at the surface of the liquid, is considerable; in fact, so great that small density changes cannot be observed with any accuracy, if at all.

The blank form herewith shown in Fig. 21 gives a good idea of the proper observations to make and method of tabulating.

In making connections, be sure that the proper polarities are joined together. Any voltmeter in which the controlling magnet is permanent will indicate the polarity and its use will obviate errors.

If the containing vessels are of considerable depth—over 20 inches—the electrolyte should be made to circulate con-

REPORT ON BATTERY PLANT.									
Number of Cells .....					Installed at .....				
Type " " .....					190 .....				
No. Plates Per Cell .....									
Glass Jars or Lead-Lined Tanks .....									
Temperature of Battery Room .....					° F.				
" " Cells at End of Discharge .....					° F.				
" " " " " Charge .....					° F.				
NO. OF CELL	VOLTAGE OF EACH CELL		SPECIFIC GRAVITY		Average Amperes Discharged Per Day	Average Rate of Discharge	Color of plates whether Light, or Dark, or Brown	Appearance of Negative	Note whether Plates are Straight
	End of Charge at .... Amp.	End of Discharge at .... Amp.	At End of Charge	At End of Discharge					
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
61									
62									
63									
64									

FIG. 21.

tinuously by some mechanical means. A simple, cheap method is to use compressed air distributed along the line of cells by means of an ordinary iron pipe, tapped with an opening opposite each cell, into which is screwed a nipple. From each nipple a small rubber pipe about three-eighths inch in diameter runs down into the bottom of the cell, and the air blowing through the electrolyte causes circulation. A stopcock is interposed between each rubber pipe, and the main distributing pipe, so that the proper quantity of air



is fed to each cell. The amount of air required is small, and the pressure low; about four pounds per square inch.

If batteries are used intermittently, and allowed to stand some time without charge or discharge, the electrolyte should be of low density, not over 1.200, and there should be about 15 lbs. of acid per 100 ampere hours.

If avoidable, never allow a battery to stand idle any length of time after discharge has taken place. If the conditions under which the battery works are such that it must stand, stop discharge when it reaches 1.85 volts.

Be always on the lookout for sulphate, and when the plates begin to turn lighter than their normal colors, locate the cause and remedy it at once, after which give the sulphated cells a good overcharge. When the density of the electrolyte becomes higher than normal, owing to evaporation, pure water must be added to bring the specific gravity to its proper value. This should always be introduced into the cell at the bottom, by means of a short length of rubber hose or lead pipe, extending down into the electrolyte. Water so put in will diffuse and mix itself with the acid, while if it were simply poured in at the top it would, by reason of its lower density, float, and would mix very slowly, if at all.

If the batteries are to be put out of commission for some time—say six weeks or more—they should not be allowed to stand in the electrolyte unless a small charge and discharge be given them at least once a week. Where they are to be unused for some time, they should be slowly charged, then discharged at the normal rate for about two hours. The electrolyte should then be drawn off, and immediately after pure water put into the tanks. The discharge is then continued, at about one-half the normal rate, until the voltage becomes very low, say .5 volts. It will be necessary to short circuit the cells to get the plates discharged in the water bath. The plates should then be washed thoroughly in running water; usually a hose played over the elements is quite sufficient. Allow to soak in water about 24 hours, and dry. When the batteries are again put into commission, it is only necessary to pour in electrolyte and give a long overcharge.

## CHAPTER XV.

### TYPES OF PLANTÉ PLATES.

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The Planté process derives its name from Gaston Planté, who, in 1860, first produced a practical storage battery by passing current through two lead plates immersed in dilute sulphuric acid. After the expiration of a considerable time, a slight coating of peroxide of lead was formed at the anode by the evolved oxygen, the cathode being unchanged. On reversal of direction of current flow, the peroxide was reduced to metallic sponge lead by the hydrogen—the peroxide element having become the cathode—and the previously un-attacked plate was peroxidized. This, then, constituted a storage battery, but of negligible capacity as the layers of active material were infinitesimally thin, owing to the fact that the action of the oxygen on the lead can penetrate no further after a layer of peroxide has been formed.

By repeatedly reversing, Planté was able to increase the depth of the coating of active material sufficiently to produce a storage cell that compares favorably with any battery made to-day. It required, however, several months to do this, and the process is not a practical commercial one, but all processes which produce active material upon the plate, and out of the material of which it is made, are now termed Planté processes.

The various methods of finely subdividing or making up lead plates, so that their exposed surface is very great, and which are to be subjected to Planté formation, are: Scoring, grooving, laminating, casting, pressing. Also use of lead wool.

*Scoring* consists in passing scoring wheels over the surface of a lead sheet, both sides being scored at the same time. The scoring wheels are run in "gangs" of from 200 to 400,

on the same axle, the number varying with the width of the plate. Where the sharp edge of the wheel rims enter the lead, grooves are left, and between the wheel tracks the soft lead is pressed out in the form of thin ribs or leaves, and raised above the surface of the plate. By making the ribs very

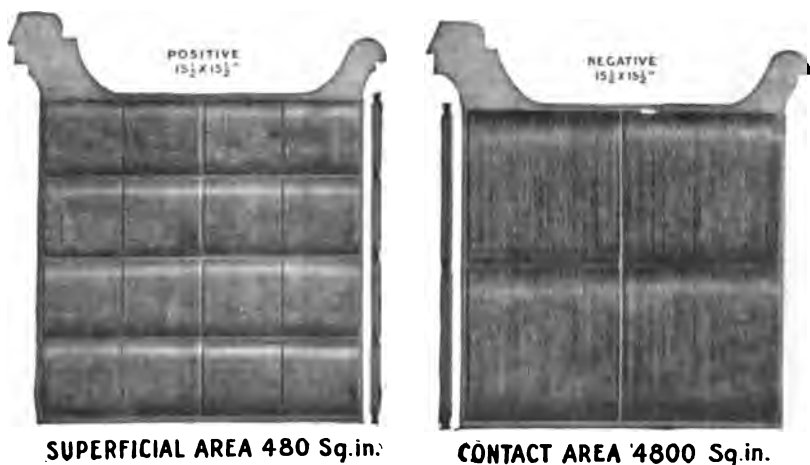


FIG. 22.

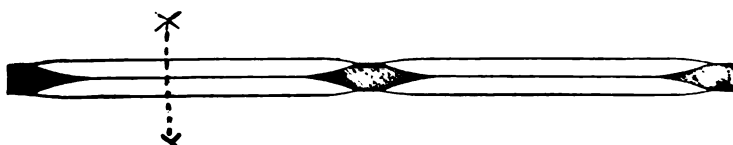


FIG. 23.

thin, thereby getting a great number in a given size plate, a large area is produced.

Figs. 22 and 23 show the Gould Storage Battery Company's plate, which is made in this manner; Fig. 23 being a vertical section. The effective area is twenty times the original area of the plate, when the grooving is very fine. The thinnest ribs are .012 inches thick, while the heaviest grooving produces ribs .024 inches in thickness. The grooving is varied between these limits, the thickness of the ribs being made to suit the conditions under which the battery is to operate.

Plates so made have the advantage of being a single integral mass, without joint or contact, and of allowing expansion to a reasonable extent. The web which is left in the centre of the plate forms the grid, and gives conductivity.

The rising of the ribs above the surface of the plate, so that the thickness of the grooved element is greater than that



FIG. 24.

of the original sheet, is clearly shown in Fig. 23. It is also to be noted that the entire surface of the plate is not grooved. Reinforcing ribs of the solid lead are left at proper intervals, as shown in Fig. 22.

Another form of scored plate is that in which the ribbing is in the form of concentric circles, as shown in Fig. 24.

In neither of these elements is any lead removed from the plate, and they are made from a lead sheet, which is thinner than the finished plate.

*Grooving.* This consists in cutting out grooves in a lead plate, leaving ribs. The original plate must be of the same thickness as the finished plate, if the depressions are caused by removing—generally sawing away—some of the metal.

This method also produces good plates, but not so finely divided, nor with such an increase of active over original area, as does the scoring.

The Willard and American, shown in Figs. 25 and 26, are examples of the grooved plates.

It will be noted that the ribs in these plates stand out at an upward angle, the idea being to hold the active material



FIG. 25.



FIG. 26.

against dropping. No metal is cut away in these plates. The ribs are raised with a tool from the lead sheet.

*Laminating* consists of forming a plate of lead ribbon, these usually being alternately flat and corrugated. The plates of the National Battery Company, shown in Fig. 27, are of this character.

These strips, or ribbons, vary from .015 to .020 inches in thickness, and are one-quarter inch in width, this being also the thickness of the plate. Straight and corrugated strips are alternated, and stretch across the plate between the outer ribs of the grid. Reinforcing ribs are placed on the plate, running lengthwise and crosswise, the number varying with

the size of the plate. These ribs are sunk into grooves which are pressed into the plate, so that they do not project above its surface. The strips are all heavily knurled, and the method of construction gives a solid element of great active area per square inch of plate. The strips are welded to the grid at the ends with an oxyhydrogen flame.



FIG. 27.



FIG. 27A.

This plate possesses the advantage of affording free and rapid circulation of electrolyte.

The deKabath elements are also made up of alternate flat and corrugated laminæ, in much the same manner.

The D. P. Battery, made by Drake & Gorham, is shown in Fig. 28. The laminæ are straight, and their ends are connected by casting a lead bar or rib on each side of the plate as indicated. It is to be noted that the side bars are not held together at the top and bottom by cross bars. This construction allows the plate to expand freely with discharge and to contract on charge.

The Manchester plate, made by the Electric Storage Battery Company, and shown in Fig. 29, is made by rolling

lead ribbon into spirals and inserting the resulting "buttons" into circular holes, which are cast in the supporting grid. The lead ribbon is smooth on one side, but ridged on the other. When the plate is formed, the expansion of the active buttons causes them to firmly wedge themselves in the holes, and the necessary mechanical contact is secured. The oxydization of the buttons, however, prevents metallic contact between them and the grid, and the conductivity is therefore not so high as in certain other forms of plates.

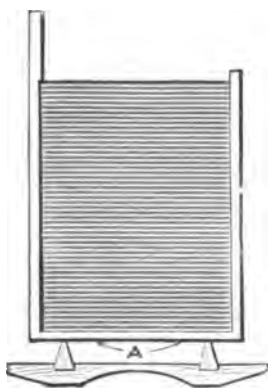


FIG. 28.

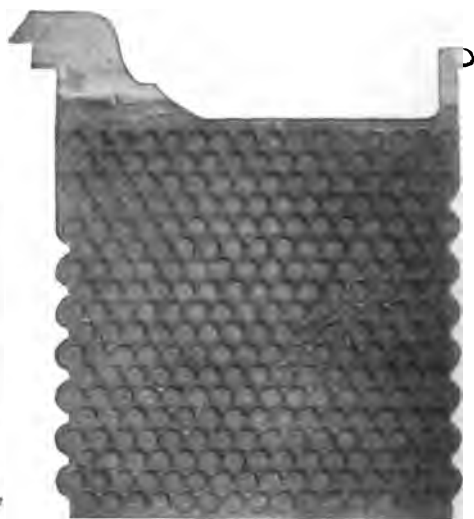


FIG. 29.

Some Planté elements are made by casting the plates in dies, which leave the surface finely ribbed or otherwise divided. The plates of the Aktien Gesellschaft Hagen and the Oerlikon Co. are examples of these. A cross section of the Hagen plate is shown in Fig. 33.

The cast plate of the National Battery Co. is shown in Fig. 27-a, the plate and ribs being a complete integral mass. Expansion and contraction are not hindered and the conductivity between the support and the ribs is the highest obtainable. The casting is done under heavy pressure to insure a density and freedom from blow holes and defects.

Lead wool plates were made by Simmen, by pressing together fine lead wire, cut up and thrown into a die. This was not, however, a successful plate, owing to its liability to fall to pieces from expansion and contraction, and poor conductivity.

A special type of Planté element is that of Prof. William Main. It consists of a pile of thin lead sheets about .012 inches thick, perforated with numerous holes. The outer laminæ are about .1 inch thick and made of antimonious

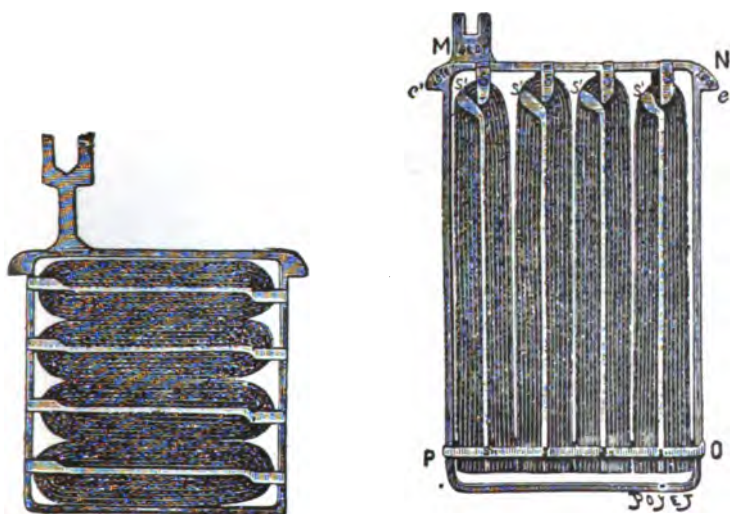


FIG. 30.

lead. The pile is fastened together with lead rivets and the plate then perforated with numerous holes; before assembling the sheets, each is covered with a layer of magnesium sulphate which dissolves out and leaves a space between each sheet and its neighbor. The electrolyte can therefore penetrate every portion of the surface of the laminæ and in this way the active area per plate is large.

The Blot battery is made up of laminations fashioned into long hanks. The laminations are alternately flat and corrugated, and all knurled.

The length of a hank is twice the length of the plate, into



which it is to go, and about  $1\frac{1}{4}$ " wide. The thickness of the plate, corresponding to the width of the lead ribbon forming the hanks, is  $\frac{3}{8}$ ". The thickness of the lead ribbon is  $\frac{1}{2}$  m. m.

The hanks are wound about two narrow forked pieces at either end, these latter being made of lead-antimony alloy. When finished, the hanks are cut in two across the middle. The plate is made up by joining these half hanks to the upper

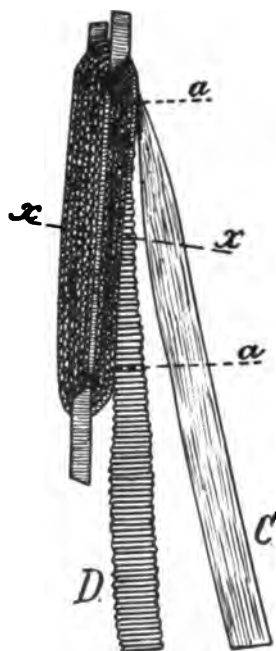


FIG. 31.



FIG. 32

bar of the plates, the end carrying the forked piece being fastened to the bar by soldering or burning the latter onto it. The laminæ are also joined at the same end by welding them together solidly. The lower ends hang free and are prevented from moving sideways out of the plane of the plate, by cross bars on each side. This does not interfere with the longitudinal expansion of the hanks, and the ideal conditions are most nearly met by this construction. Figs. 30, 31 and 32 show the plates and their construction.

The foregoing are only a few of the most important methods of making up plates for Planté formation, but illustrate practically all of the types.

For more extended data and descriptions of these and other forms of plates, no better references are to be had than the trade literature of the various storage battery manufacturers throughout America and Europe.

In making up plates for formation, much careful experimenting must be done to find just how far the plate may be subdivided. Too many ribs or laminæ will allow the formation of more oxide than the plate can carry, and result in "buckling" or forcing out in the form of shallow pockets,

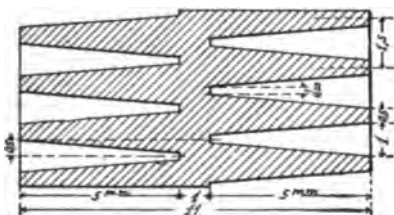


FIG. 33.

certain portions of the plate. When the plate has expanded to its limit, and more material still forms in the plate, expansion must take place in a direction perpendicular to the plane of the plate, thereby distorting it.

If, on the other hand, the plate be not subdivided sufficiently, the area exposed will be small, and the capacity of the plate correspondingly limited. There is some particular number of ribs or laminæ in each type of plate, that gives the greatest possible capacity, within the limit of buckling or distortion. The depth of the layer of peroxide is a function both of expansion and plate capacity, and the number of subdivisions may be large with a thin formation, or small with a thick formation. It is in many respects desirable to have the formation as thin as practicable, and a large number of laminæ. A thin layer of active material gives a more uniform voltage on discharge, admits of more rapid charge

and discharge, and for batteries where the current rates are high, the thin layer is especially applicable.

The active material, however, expands and contracts with discharge and charge, and a thin layer offering a greater surface, must undergo a correspondingly greater degree of expansion and contraction than a thick formation, and therefore is more liable to peel off from the supporting ribs. From this, it follows that batteries which are to be charged to their fullest capacity and then discharged continuously to the minimum voltage, should be thickly formed.

## CHAPTER XVI.

### METHODS OF PLANTÉ FORMATION.

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In the methods of formation to be described the lead is attacked and finally converted into lead peroxide, probably passing through intermediate stages. After being fully formed as positive plates, all that are intended for negatives are reversed, the peroxide being changed into sponge lead.

Sheldon and Waterman have shown, by a very interesting experiment,\* that as the Planté process of formation proceeds, in sulphuric acid, the lead is first changed into lead sulphate, and afterwards into lead peroxide, an appreciable time element elapsing between the first and second stages.

The experiment consisted in passing alternating current of various frequencies through two electrodes immersed in dilute sulphuric acid, and noting the frequency and resulting deposit. At low frequencies the deposit was brown peroxide, and at high frequencies, white sulphate only was produced, which fell from the plates as fast as formed. In the former case, the time of one impulse was long enough to form sulphate and change it into peroxide; in the latter, the impulse lasted only long enough to form the sulphate, which was thrown off on the succeeding impulse in the opposite direction.

The methods of rapid or autogenous Planté formation may be classified as CHEMICAL, ELECTRO-CHEMICAL, ELECTROLYTIC and AMALGAMATING.

The electro-chemical may be sub-divided into three groups:

The first group is that in which one of the acids which dissolve lead, or a salt, the acid of which belongs to the lead

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\*"The Formation of Lead Sulphate in Alternating Current Electrolysis with Lead Electrodes." Samuel Sheldon and Marcus B. Waterman, *Physical Review*, No. 22, Vol. IV (Jan.-Feb. 1897).

dissolving class, is used in combination with some sulphate or carbonate.

The principal acids which dissolve lead are chloric, nitric and acetic.

When these lead solvents are used, there must also be present a carbonate or sulphate, to act as a re-depositor of the lead which is dissolved by the acid. There can be many combinations of lead dissolving acids with carbonates and sulphates, a mixture of any of these being substantially the same in its effects. The difficulty with this character of formation, is to rid the formed plate of the last traces of the acids which attack the lead. Unless these acids are completely removed, the forming process will continue during the use of the plate, with the result that the plate is soon eaten away.

The second group of electro-chemical formation, is an accelerated Planté process, in which the necessity of repeatedly reversing the current through the plates, is obviated.

The second group of electro-chemical formation is based on the theory that two peroxides which are present in the same solution, tend to discharge each other. Therefore, if a formation proceeds in dilute sulphuric acid to which some peroxide has been added, the lead peroxide which forms on the surface of the plate, by reason of the electrolytic action, is deoxydized by the peroxide which has been added to the electrolyte. This deoxydization takes place almost simultaneously with the primary oxydization, which is practically equivalent to the continuous formation of lead sponge. The formation is therefore continuous, and does not require reversals of current.

The third group comprises the miscellaneous electro-chemical formations not included in either the first or second group.

In processes to be hereafter mentioned there are, in many instances, specified proportions given of the chemicals which are used to make up the electrolyte. In very few instances, however, will these proportions be found correct, as the inventors usually specify wrong proportions to mislead competitors, and only reveal the chemicals used, there being

nothing further than this required to protect their process. For this reason, the proper proportions will generally have to be found by experiment. The importance of having the chemicals mixed in exact proper proportions, is shown by some tests recently conducted in Germany.

As an instance, the following is given:

Solution made up of 10 cu.cm. of sulphuric acid; 10 cu.cm. of nitric acid of 1.18 sp.gr.; this mixture diluted with water. The deposit of oxide of lead per 100 ampere hours in this electrolyte was 0.1837 grams.

Using the same dilution of electrolyte, but taking 12 cu.-cm. of sulphuric acid and 10 cu.cm. of nitric acid, the deposit for 100 ampere hours was 108 grams. or six hundred and fifty times as much for a ten per cent. variation of the electrolyte.

The mechanical structure of the lead sponge which is produced electrolytically, can be altered by additions to the electrolyte; if formed in clean, dilute sulphuric acid, with high current density, a sponge results which, on being dried in closed vessel from which air is excluded, gives a fine, brittle powder. If formed in glycerine sulphuric acid, other conditions being the same, a fibrous, felt-like structure results. In the same way, the crystalline structure of the superoxides may be altered. These forming baths may be acid, alkaline or neutral, according to the character of the sulphate or carbonate used and the proportion thereof used in the solution.

When formation takes place in neutral solutions, an important superoxide hydrate of lead is formed, which gives great hardness to the active material. Additions, like mercury sulphate, favor the formation of proportionately harder superoxides, probably through the retardation of the changes in the sulphuric acid by the mercury salt.

As a general rule, the higher the temperature of the electrolyte, the less fast to the supporting conductor and the less hard is the resulting superoxide deposit. This also becomes more brittle and harder the lower the current density, other conditions being the same.

Of the various processes, the electro-chemical seems to

offer the best method for producing a durable plate, of high capacity and efficiency.

It may be remarked here that, theoretically, the Planté plate is not so suitable for the negative as for the positive electrode. The reason for this is that the active material on both plates degenerates by losing contact with conducting support, filling of pores and sulphatation. On the negative plate there is no action which tends to rejuvenate the active material, while on the positive, the oxygen set free on charge always keeps the latter plate well covered with active material, and in case of loss of active material, a new peroxide coating will form.

The negative plate, having no such re-formation process, decreases in capacity continually, from the time it is put into service, while the positive increases up to a certain limit, after which it, too, begins to decrease in capacity, but very slowly. It must, therefore, have a higher capacity than the positive when the battery is first constructed, usually from 25 to 50 per cent. excess is given in practice. This does not mean that there is more active material on the negative than the positive elements. Quite the contrary is true, and if the plates should be discharged down to zero voltage, the positive plates would often show a higher capacity than the negatives.

The negative capacity from full charge down to 1.7 volts should be from 25 to 50 per cent. greater than the positive, is the requirement, and owing to the greater porosity of the lead sponge, this is accomplished with the use of less material.

Since most troubles at the negative plates come from the expansion and contraction of the active material, it is necessary to have the area of this material as small as possible, and the formation should therefore be thicker than on the positive. The pasted plate offers a smaller area for the same quantity of active material, and therefore is considered more suitable for negatives than the Planté plate. There are, however, many successful batteries in operation having Planté negatives.

Before taking up the various methods of formation, it is well to note the results obtained in the tests previously men-

tioned, which were made in Germany, to determine the rate of deposit of lead peroxide per one hundred ampere hours, for different classes of electrolytes. The experiments were incomplete, in that nothing was given to show the character and physical structure of the peroxide after it was formed, or whether it adhered solidly to the conducting support, both of which are even more important than the quantity deposited. They, however, give an idea as to the best lines of experimentation to follow up:

1.003 Sp. gr. sulphuric acid. Deposit, .7683 grams  $\text{PbO}_2$ .

1.028 Sp. gr. sulphuric acid. Deposit, .7066 grams  $\text{PbO}_2$ .

Electrolyte composed of 1 Litre of water; 24 cu.cm. sulphuric acid; 50 cu.cm. of methyl alcohol. Deposit per 100 A.H., 3.748 grams  $\text{PbO}_2$ .

One Litre of water; 500 cu.cm. of sulphuric acid sp.gr. 1.152; 50 grams of ethyl alcohol. Deposit, 5.664 grams.

Twenty-four cu.cm. sulphuric acid; 10 cu.cm. hydroxyl amin sulphate; 1 Litre of water. Deposit, 28.5 grams. Note that this experiment, through the hydroxyl amin sulphate, will produce some nitric acid in the electrolyte.

Formic acid, with sulphuric acid; proportions not stated. Deposit, 21.326 grams.

Acetic acid, with sulphuric acid; proportions not stated. Deposit, 129.4 grams.

Potassium nitrite with sulphuric acid; was tried, but the experiment failed.

Nitric acid and sulphuric acid. The result of these two tests previously given, as an example of the necessity for proper proportions of mixture.

3.5 grams potassium chlorate; 50 grams crystalline ammonia sulphate; 50 per cent. sulphuric acid. Deposit, 100.6 grams.

Ten grams potassium chlorate; 50 grams crystal sodium sulphate, with very little sulphuric acid. Deposit, 121.6 grams.

#### CHEMICAL PROCESSES.

##### 1. ....

The most extensively used chemical process is that in which a porous layer is produced on the surface of the lead



plate, by the action of dilute nitric acid. The acid should be very weak, usually about one per cent. of the mixture, the specific gravity at 60° F. being from 1.005 to 1.006. About one quart of the fluid to every square foot of the lead surface is required. The plates are immersed in some vessel which will not be attacked by the acid, such as salt glazed stone ware, and the temperature is then raised to the boiling point of the liquid. This is maintained for a period of about twelve hours. The plates are then removed and exposed to the air, and after that again immersed and boiled for a short period, about seven hours. After removing the second time, the plates are washed with hot water, and afterward in very dilute sulphuric acid. They are then formed in fresh sulphuric acid electrolyte, of specific gravity of about 1.15. The electrolyte in which the plates are formed should never be used when the plates are put into practical operation.

The objection to this process is that it is very difficult to remove the last traces of the nitric acid, and if any of it remains the active material is caused to flake off from the conducting support, due to the corrosion of the underlying metal.

## 2. SWAN.

This is probably the oldest of the chemical group. Lead plates are coated with a layer of white lead, by the well-known Dutch process for the manufacture of white lead, namely, the action of carbonic and acetic acid vapors on metallic lead. After the layer has become thick enough, the white lead is reduced to metallic sponge lead. This is done by forming the plates in an ammonia sulphate bath, using them as cathodes. Dummy plates are used for the anodes. The hydrogen liberated at the cathodes changes the white into sponge lead.

This is not considered a satisfactory chemical process, as it is somewhat expensive, and traces of the acetic acid are usually left behind and cannot be eliminated. These, of course, cause the plate to disintegrate when put in service.

**\*3. EPSTEIN.**

The formation under this process is as follows: Lead plates are placed in a ten per cent. solution of nitric acid and water, which is maintained at a temperature of 100° C. for several days. When the coating is about 1 mm. thick, the plates are dried in the air. The nitric acid is removed by forming in dilute sulphuric acid electrolyte, which contains some copper sulphate. The plates in this case are connected as cathodes, dummy plates being used as anodes. The surface finally is reduced to spongy lead, and the plates are then formed further in dilute sulphuric acid, containing pyro-tartaric acid. Under this last formation, the grayish-yellow color of the plates is changed to a dark brown.

The objection to this method is that not only nitric acid or carbonic acid combinations may be left behind after the formation, but the pyro-tartaric acid will probably release some acetic acid under the electrolytic action, all of which would cause the plates to go to pieces in a short time. Also copper, from the copper sulphate, may be plated onto the cathodes.

**†4. LUCAS.**

Under this process, the plates are first treated with dilute nitric acid at a high temperature. The nitric acid is then removed by being exposed to ammonia gas. This gas combines with the nitric acid and forms ammonium nitrate, which is evaporated at high temperatures. The plates are freed from it by heating up to 200° C. and even higher, the temperature sometimes reaching within a few degrees of the fusing point. Though it is not mentioned in Lucas's patent, it is presumed that this ammonia gas is sent into the plate under pressure, in order to thoroughly penetrate all the pores.

While this method is open to the objections previously noted where nitric acid is used, it appears to be one of the safest and best of the chemical processes.

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\*American Pat., No. 425,999.

†German Pat., No. 69,483.

\*5. SCHULTZE.

A layer of lead sulphide is formed by putting lead plates into iron boxes, which are afterwards filled with sulphur, and subjecting them to heat, the process being very similar to that of case hardening. The plates are then formed as usual, in dilute sulphuric acid.

Another method of forming the lead sulphide is by mixing sulphur and water into a thick paste, with which the plates are covered and then heated up. In any case, the heating must be gradually and carefully done, and the final temperature maintained as constant as possible.

This process is theoretically very good, as there are no objectionable or lead attacking acids introduced. It was found, however, too expensive for commercial use, given up by the patentee, and the patent allowed to expire by reason of non-payment of taxes thereon.

6. PAGET.

In this the lead plates are boiled in dilute nitric acid, after which a head-piece and tail-piece of type metal are cast on. The plates are then subjected to the action of a heated solution of nitrate of magnesium, after which they are assembled and formed by passing a current through them in a bath containing the double sulphate of magnesium and ammonium. They are then reassembled in another cell containing the usual dilute sulphuric acid, and put in commercial use.

7. STARKEY.

In this a small amount of chromic acid is added to the dilute sulphuric acid. It is stated that plates formed in this bath set harder and quicker, and become more deeply peroxylized than in ordinary acid, and that their durability is most satisfactory.

8. DUNCAN.

In this process the plates are cooked in a solution of litharge in caustic potash or soda. A thick, dense deposit

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\*German Pat., No. 21,454.

of spongy lead results, which is afterwards formed in the usual manner.

\*9. WUILIOT.

In this, the surface of the lead plates is transformed into lead carbonate by the action of nitric or acetic acid vapors in the presence of carbonic acid, or solutions of carbonic acid. This latter is reduced to sponge lead by passing current through the plates as cathodes, dummy plates being used as anodes in an alkaline bath, either of sodium carbonate or sodium hydrate.

10. RECKENZAUN.

By this method, the lead plate is oxidized by means of an electric arc. The electric arc is drawn between the lead plate and a carbon electrode. As the electrode is moved along and over the plate, the oxydization takes place on the lead surface. This method gives a positive adherent layer of oxide, but the expense and difficulty of the process makes its use practically prohibitive. In any event, it can only be used on plain, flat lead sheets, and not on corrugated, ribbed or otherwise finely divided lead surfaces.

ELECTRO-CHEMICAL PROCESSES.

*First Group:*

†1. VAN DE POELE.

In this process, lead plates are cleansed by plunging into a mixture of nitric and sulphuric acids, diluted with water. Afterwards, they are formed in a bath of a mixture of these acids, less diluted than the cleaning bath. They are then washed in running water, and further formed in a bath of dilute sulphuric acid. In this last formation, nitrate of lead, which was previously formed, is decomposed, and peroxide formed on the negative electrode. Peroxide of manganese is then added, either to the electrolyte, or the plates are removed and the peroxide sprinkled on them. They are then

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\*German Pat., No. 36,237.

†American Pat., No. 282,414.

placed in a dilute sulphuric acid forming bath, and the formation completed.

The before mentioned objections to any system using nitric acid or chloric acids, applies to this, namely: the difficulty of ridding the plates completely of the last traces of the lead dissolving acid.

\*2. CUTTRISS.

In this system, the plates are formed by the electric current in a bath made up of sulphuric and nitric acids, and a small amount of potassium bicromate, diluted with water.

3. LUCAS.

†(a) This patent covers the generic class which is now being described, namely: the use of any acid which dissolves lead, or any salt, the acid of which is a lead solvent, combined with a sulphate or carbonate to re-deposit the dissolved lead back on the plate from which it is taken. In this patent, chloric, nitric or acetic acids are mixed with sodium sulphate, sodium carbonate or magnesium sulphate.

(b) In a *German Patent*, No. 90,446, Lucas described the use of perchloric acid or its salts, instead of chloric acid. This is a useless method, for the reason that the chloric acid is largely converted into perchloric acid under the action of the electric current, and this, therefore, is no improvement over the former method of using chloric acid and its salts.

4. SWINBURNE.

In this process, a mixture of acetic acid and dilute sulphuric acid is used, as the forming electrolyte. The acetic acid is removed by subjecting the plates to the action of heat, the temperature being about 200° C., it being supposed that at this temperature all the acetic acid will be evaporated.

The objections mentioned, with regard to nitric acid formation, of course apply to this.

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\*American Pat., No. 261,435.

†German Pat., No. 82,730.

## 5. DUJARDIN.

In this method, an electrolyte is used of dilute sulphuric acid, one-half saturated with sodium nitrate (Boettcher recommends the addition of a small amount of acetic acid to the solution). The proportions given are: 1 Kilo sodium (or any alkaline) nitrate; 2 Kilos sulphuric acid; 10 Kilos water. The solution really becomes one of an alkaline sulphate with free nitric and sulphuric acids, so that the formation is practically identical with others previously mentioned. The nitric acid which is formed becomes deoxydized, but it can be regenerated by forcing air into the bath.

## 6. SCHOOP.

Dr. Schoop has produced a number of processes, which belong to this generic class, the principal ones being as follows:

(a) The bath of 5 Kilos sodium bisulphate; 100 Grams potassium chlorate; 45 Litres of water. Current is passed through at the rate of .4 of an ampere per square decimeter of anode surface. After removing from the forming bath, the plates are put into sulphuric acid electrolyte of specific gravity of 1.100, and the current passed through in a direction opposite to that used in the first bath, hydrogen being developed on the brown plates. Dummy plates are used for the opposite poles. This second change is for the purpose of removing the chlorine, and the electrolysis is finished when the brown plates become gray. These plates are then removed, washed well in water, and dried in air. They are afterwards further completely dried at a temperature of 200° C. The plates will be now found to have a covering of lead sponge, which is transformed to peroxide in an electrolyte of five per cent. sulphuric acid, the current density being one ampere per square decimeter. The uniformity of the layer formed is increased by blowing air into the liquid. The temperature should be maintained between 25° and 35° C. Time of formation, about one hundred hours.

Similar results he obtained with the same mixture, more dilute, using about twice the amount of water. The time

required in the latter case, however, is about two hundred hours.

The sodium bisulphate in the first forming bath, can be replaced by sodium bisulphate (Glauber's salts) with the same relative concentration. The results, however, are not so good in the latter case.

(b) The forming bath consists of sulphate of ammonia, with hydro-fluoric acid.

(c) Solution of sulphate of lead in ammonia tartrate.

(d) Solution chlorate of sodium and sulphuric acid.

(e) Iron or zinc chlorides, with sulphuric acid.

(f) Tartrate in sulphuric acid. In this case, acetic acid is formed in a small degree from the tartrate, by the action of the current, and this is presumably the active agent.

To all these processes there are the same objections as above noted, namely: the difficulty of ridding the plates of the lead dissolving acids.

#### \*7. HARRIS AND HOLLAND.

Plates are immersed in a bath consisting of dilute sulphuric acid with nitric or acetic acids. They are then removed and subjected to the action of an electric current, in a bath made up of a moderately strong solution of magnesium sulphate, or its equivalent, such as aluminum sulphate and proportionately small quantities of sulphuric and acetic acids and magnesium acetate. The actions which take place are, the formation of lead sulphate by chemical action, and the peroxydization of this sulphate by the current; the magnesium sulphate and acetate being used to facilitate the peroxydization of the lead sulphate, which offers some difficulty to peroxydization. When the formation has penetrated to a sufficient depth, the plates are thoroughly washed, and subjected to a second formation, in a bath of dilute sulphuric acid with a small quantity of sodium or potassium sulphate. This completes the formation by converting any remaining portions of the lead sulphate to peroxide. When fully formed, the plates which are intended for negatives are connected negatively in the circuit, and current passed through them.

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\*American Pat., No. 574,417.

## 8. LUCKOW.

In this process, a forming bath of sodium chlorate and sodium sulphate is used, subsequent treatment of the plates being as is customary in this class of formation.

## 9. HERING.

This is a nitrate of lead formation, in which this chemical is mixed with the dilute sulphuric acid. This is merely an equivalent of the usual nitric acid formation, as the nitrate of lead quickly gives up its nitric acid, under the action of the electric current.

## 10.

Plates are connected as anodes, and immersed in a dilute sulphuric acid bath, dummy plates forming the cathodes. Current is passed through the plates, until a brown layer of lead peroxide is formed.

The plates are then washed, and immersed in a bath of highly diluted nitric acid, where they remain until the brown peroxide turns a gray color, after which they are removed and again connected as anodes, in dilute sulphuric acid.

This alternative treatment continues until the layer of active material becomes as thick as desired. The solution of nitric acid should be in the proportion two to three per cent. nitric acid; 98 to 97 per cent. water. If the nitric acid bath be too strong, the subsequent formation will be injured.

It is claimed that this treatment is rapid, efficient, requires but little forming current and, as the formation can be made to penetrate as deeply as desired, the resulting plate gives a high capacity per unit of weight.

Fitz-Gerald suggests that nitric acid may be completely eliminated by saturating the plates with weak solution of sulphate of ammonia and afterwards heating to about 600° F. This is near the fusing point of lead, viz.: 619° F. and the temperature must be carefully regulated to prevent its reaching the melting point of the metal.



*Second Group.*

## 1. NORDEN.

In this formation, a peroxide is added to the solution, in order to cause the continuous reduction of the formed lead peroxide to sponge lead. Norden recommends the addition of potassium permanganate, or persulphuric acid, or perchloric acid, to the diluted sulphuric acid. The first two are the best, as the last named would probably leave behind traces of chloric acid.

## \*2.

In this, the lead plates are immersed in a solution of hydrogen peroxide, several hours, and afterwards they are formed in a bath of dilute sulphuric acid, containing hydrogen peroxide.

*Third Group.*

## 1. NORDEN AND SHELDON.

In this system, an alternating current is passed through the plates, which are immersed in a sodium hydrate solution. This will cause the disintegration of both plates, provided the frequency of the current be not over 25 or 30 p. p. s. After the disintegration has proceeded to a sufficient depth, the plates are removed, placed in dilute sulphuric acid, and subjected to the usual Planté formation.

## 2. HABER.

This is the ordinary Planté formation, accelerated by the use of excessive current densities. The current is passed through the plates, which are connected as cathodes, dummies being used for the anodes, immersed in dilute sulphuric acid, the current density being 1500 amperes per square decimeter of exposed surface, or about 100 amperes per square inch. By this method the formation is completed within a few minutes, between 20 and 30, and there are left behind no traces of any lead attacking acid. The total

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\*Hungarian Pat., No. 19,427.

electrical energy required, however, to complete the formation, is about ten times that required for ordinary formation, and this process, therefore, is suitable only for localities where labor and the cost of handling are very high, and the cost of current low.

**\*4. SÄCHSISCHE ACCUMULATOR WERKE.**

This is a quick formation process, in which highly diluted sulphuric acid is used, to which is added sulphuretted hydrogen ( $H_2S$ ). This process yields excellent results, but it has the objectionable feature that the sulphuretted hydrogen fumes which are evolved during the formation, are not only highly objectionable on account of their odor, but to a certain degree poisonous. It therefore has not been taken up commercially in Germany, for the reason that the German factories have never really prepared themselves to manufacture with this process, by making fume-tight rooms, and ventilating the same properly.

From the excellent results which plates so made would seem to give from theoretical considerations, it would appear that this would be an excellent system, if the factory details for carrying on the formation in gas-tight rooms, could be properly worked out.

**5. BECKMAN.**

In this process, the plates are formed in an electrolyte consisting of a saturated solution of sulphurous acid in water. Sulphurous acid being a gas, the formation must take place under pressure, in order to prevent the gas from escaping from the electrolyte.

This is a quick formation process, and gives good results. There are no objectionable elements left which will attack the lead. The sulphurous acid,  $H_2SO_3$ , passes into sulphuric acid,  $H_2SO_4$ , under the electrolytic action.

**†6. LUCKOW.**

The forming bath in this process is alkaline; may be am-

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\*German Pat., No. 127,275.

†English Pat. No. 24,960.

monia or hydroxide of potassium, sodium, calcium, or baryum. The solutions must be very highly diluted, one-tenth of one per cent. being given as the best percentage of mixture, and three-tenths of one per cent. being given as the maximum percentage. As an example, the following mixture is given: 5 Litres water; 20 cu.cm. caustic soda of specific gravity 1.13.

When this electrolyte is made up, and formation begins, the bath must be excluded from air, in order that carbon dioxide ( $\text{CO}_2$ ) may not combine with the alkali. Anything which will absorb the carbon dioxide may be put in the forming room, such as pieces of calcium hydrate. The forming voltage is generally above two volts, and is said to rise up to three volts. Current density is ten to twenty amperes per square meter of anode surface, though higher densities may be used, if desired. The temperature at which formation takes place should be moderate.

At first, the lead hydroxide which is formed on the positive plates, falls to the bottom of the cell, but as the electrolysis proceeds, a good, soft, porous layer of lead hydroxide forms on the plate. This goes into lead oxide ( $\text{PbO}$ ), and then into lead peroxide ( $\text{PbO}_2$ ). After continuing the operation for eight days, the poles are changed, and current passed through in the reverse direction, for six days. If desired, the operation may be continued for only four days, then reversed for three days, then again passed in the first direction four days, and again reversed for three days. With an increase of concentration of the electrolyte, the intensity of the process is diminished.

After formation, the plates are washed thoroughly in running water, and then subjected to pressure to remove the water. The positive plates are then further formed forty-eight hours in dilute solution of potassium carbonate, in order to completely peroxide those particles which may not have been peroxydized in the first formation. This potassium carbonate battery should be of good conductivity, and the current density of the second formation should be double that of the first formation. After removing from the second

bath, the plates are washed thoroughly, and are then ready to put into commission.

## ELECTROLYTIC PROCESSES.

## 1. CLARK.

Litharge is dissolved in a boiling alkaline solution of from 1.285 to 1.320 specific gravity, in the proportion of fifteen to twenty grams of litharge per litre of solution. The bath is ready to use when it is cooled down to 70° C. The lead plates are then immersed therein, and attached to the positive pole of the forming circuit. Dummy plates may be used, or the containing vessel itself, as the cathode. At a temperature of 70°, three or four hours is sufficient to transform the surface of the plate into sponge lead, though if the bath be too hot the oxide deposited may be re-dissolved. If the temperature of the bath falls to about 15° C., a coating of lead peroxide is formed, which is velvety in appearance, and adheres strongly to the lead, though the action is not so rapid as when the bath is hot.

It may be stated here, that after many experiments along the line of deposition of sponge lead from litharge dissolved in alkaline solutions, the author has become fully convinced that no successful battery plate can be so produced. Even compacting under the hydraulic press will not prevent rapid softening and disintegration after very few discharges.

## 2. M. DE MONTAUD.

In this process, the plates are coated with electrolytic lead, from a solution of lead oxide, *e. g.*, litharge, in potassium and water. In this, the current deposits a layer of peroxide of lead upon the anode, while the cathode is covered with reduced lead. Currents of high density are used, the liquid being heated to about 100° C. It is not stated whether this heating is due to the high current density, or from an outside source. The time of formation is given as thirty minutes. After removing from the bath, the positive plate, which is covered with a thick layer of peroxide of lead, undergoes several washings, and is then mounted with the negative plates in the accumulator, and charged; the negatives being

previously washed and preserved under water, to prevent the exclusion of air, and finally subjected to heavy pressure before assembling.

Dr. d'Arsonval states \* that the Montaud accumulator is unusually durable, and that the adhesion of the peroxide is such that to detach it a hammer and anvil were required.

### 3. SYLVEY.

Plates are formed by passing a current through them while immersed in a bath of acetic acid and potassium. This decomposes the anodes, depositing them in a metallic state, on the cathodes. The cathodes are then removed, and the deposit compacted by pressure, after which the plates are placed as positives in the cell.

### 4. DUNCAN.

In this process, the anodes supply lead, which is transferred to, and deposited on, the cathodes, in a bath containing a solution of oxide of lead, in potassium.

## AMALGAMATING PROCESSES.

### 1. SELLON.

In this process, lead is amalgamated with mercury, formed into plates, and the mercury is afterwards extracted electrolytically by passing a current through the amalgamated plates as anodes, in a sulphuric acid bath.

### 2. SCHOOP.

(a) Lead plates are formed in an electrolyte of sulphuric acid, to which mercury sulphate has been added. In this it is presumed that the mercury in the mercury sulphate amalgamates with the lead, and afterwards must be expelled by electrolysis. This has the advantage over Sellon's process, of amalgamating only the surface of the plate.

(b) The lead is alloyed with aluminum, the latter metal being dissolved out by immersion in hydrochloric acid.

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\*See "The Lead Storage Battery," by D. G. Fitz-Gerald.

(c) This method is the same as the one just preceding, except that the alloy is of lead and zinc.

There are many methods of amalgams in which lead is amalgamated with cadmium, potassium, or any metal which can afterwards be dissolved, and then extracted. These processes, however, have never proved satisfactory or practical, as traces of the alloying metal are, in every instance, left behind. The only one which appears to offer any prospect of success is that of SCHOOP (a), where the amalgamation takes place only on the surface, and does not penetrate into the plate.

It is not to be supposed that this chapter covers every known method of PLANTÉ formation. It gives, however, most of the important and well-known processes, though, as previously stated, the proportions of chemicals used are in many cases probably incorrect.

It may be remarked that, after a system of formation has been perfected for a given type of plate, it does not always follow that this formation can be used satisfactorily on plates of other types, and it is sometimes difficult to transfer a formation process from one type of plate to another. The reason lies in the differences of exposed area, ability to hold the active material and amount of subdivision of the plates.

In a paper presented before the A. I. E. E., May 16, 1894, by the late Mr. Griscom, he gave the results of some experiments which were made to determine the relative capacity of identical plates in the same cell. A cell having five positive and six negative plates was tested in which the plates of like polarity were not joined directly together, but were connected, each set, to a common bus bar, with a resistance interposed between the plate and the bus bar. In this way, he was able to examine the behavior of individual plates all joined in parallel and operated as a single cell. He discovered that plates made of identically the same material, subjected to the same treatment and, so far as it is possible, made in every respect exactly alike, there was quite a difference of capacity. This difference ran as high as 30 per cent. on discharge down to 1.8 volts and when discharge is pushed below this point the difference became even higher. This

difference in capacity resulted in a discharge of a positive of high capacity into those of low capacity. He explains the phenomenon by stating that the low capacity plate keeps on discharging, but at a lower rate, than the higher capacity plate, and finally reaches a much lower E.M.F. On opening the circuit the plate which has not been discharged so far rapidly recovers a higher voltage than its neighbor and therefore discharges into it.

## CHAPTER XVII.

### FAURE SYSTEM.

In 1880, Camille A. Faure produced the storage battery "pasted" plate, consisting of an antimonious grid, to which the active material was mechanically applied. The original Faure cell had both the positive and negative plates coated with minium (red lead) which is a peroxide of lead  $\text{Pb}_2\text{O}_3$ . A comparatively short time was required to reduce the  $\text{Pb}_2\text{O}_3$  to  $\text{Pb}_2\text{O}_4$  (or  $\text{PbO}_2$ ) when connected as

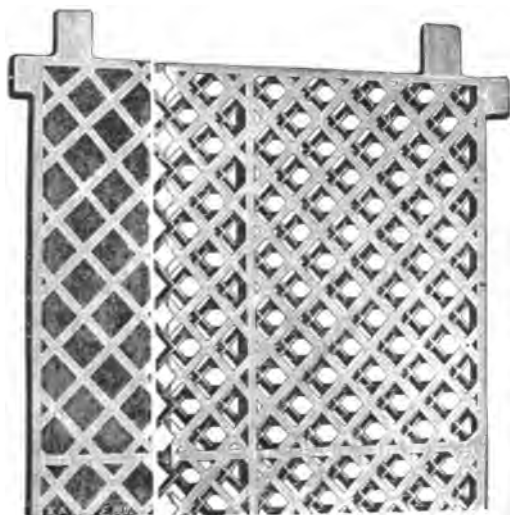


FIG. 34.



FIG. 35.

an anode, or to Pb when connected as a cathode, and the finished elements were of high capacity per unit of weight.



In this latter respect the pasted plate battery is superior to the Planté. All batteries in which a minimum weight is required can best be produced by the Faure system. It has the disadvantage, however, that the positive plates lack durability, the active material having a tendency to "shed" or drop away from the grid.

This trouble has been partly overcome by the use of en-

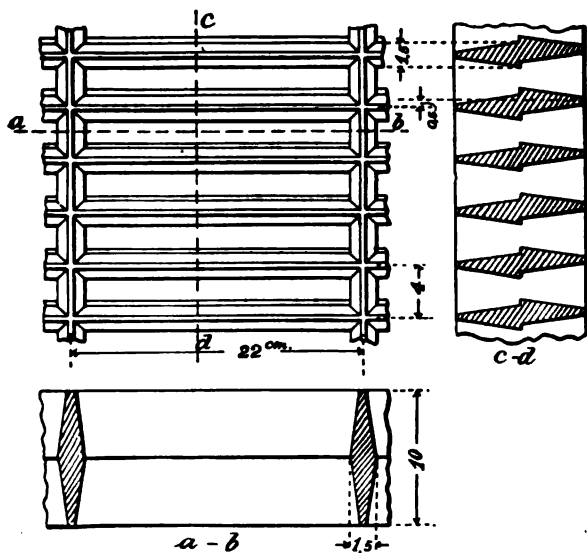


FIG. 36.

*velopes* and shaping of grids to hold more firmly the applied material.

When envelopes are used, each positive element is covered with a fabric which is wound tightly about the plate, and holds firmly into position the active material. This covering is thin and easily penetrated by the electrolyte, and therefore offers no obstruction to chemical electrical action.

Numerous types of grids and varieties of active material have been devised and are used in the manufacture of Faure batteries. So great is the number that only the most important ones can be described here.

## TYPES OF GRIDS.

## (A) GRIDS FOR PASTING.

(1) *Framework of perforated sheets or lattice work which is double, and in which the openings on the two sides of the plate do not come opposite one another.*

To this first type belong the Correns, the Accumulatoren Fabrik. A. G., and the Kayser. Fig. 34 shows the first named plate in detail and clearly illustrates the type. The active material is put into the space between the two lattices which

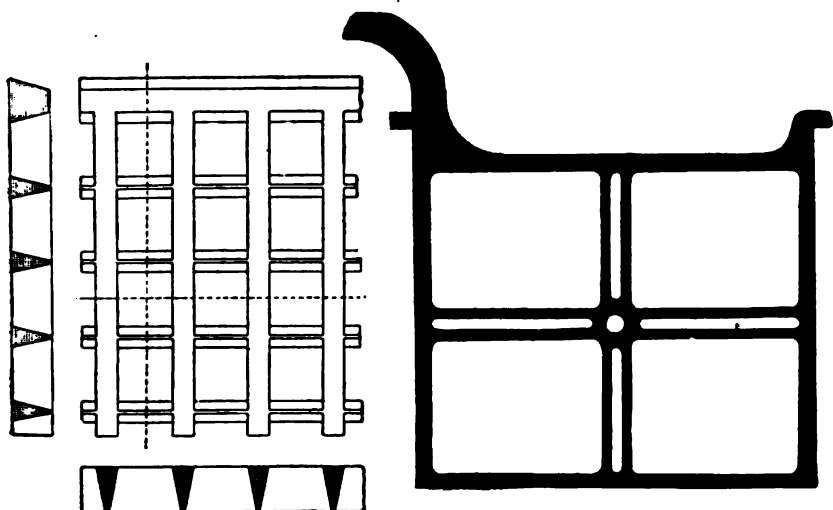


FIG. 37.

FIG. 38.

form the sides of the plate, being firmly compacted and pressed tightly against the ribs. When finished, the plate is smooth and solid, the active material being flush with the outer surfaces of the latticed sides.

(2) *Solid Perforated or Lattice work Plates.*

To this class belong the Electric Power Storage Co.'s grid, a cross section of which is shown in Fig. 35, the negative grid of the Hagen Co., Fig. 36; the Hartung negative, Fig. 37; the Böse, Fig. 38. This last named grid is provided with expansion slots as may be seen. These slots are not



FIG. 39.

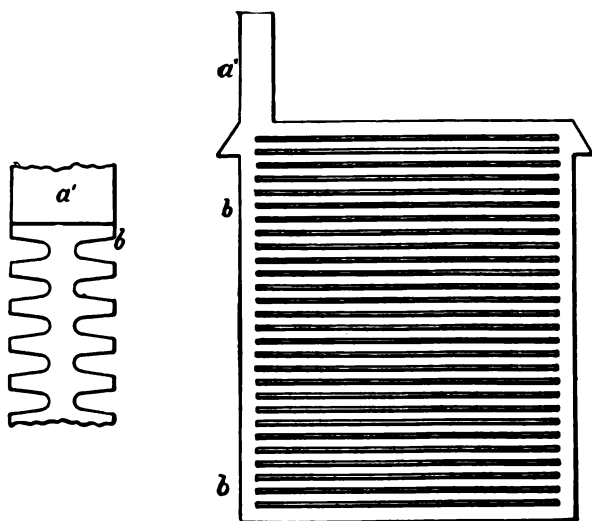


FIG. 40.

filled with active material, but left open to give flexibility to the grid.

The Exide positive grid is shown in Fig. 39. Its vertical ribs are spaced unevenly, bring closer together on the side

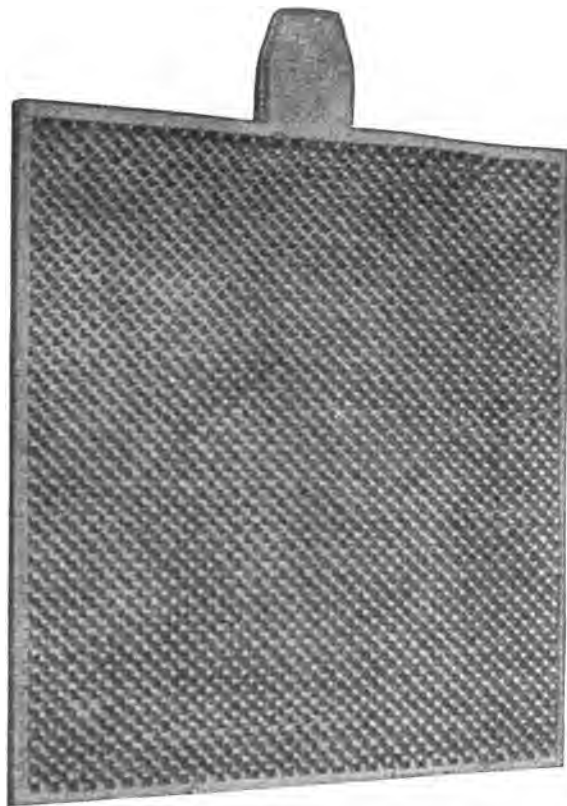


FIG. 41.

of the plate away from the terminal lug. This is for the purpose of giving better conductivity at the points furthest from the terminal, and to effect the even distribution of current over the surface of the plate.

As may be seen, the sizes of the openings in the plates vary widely, and the designers' judgment seems to be the

only determining factor as to the maximum area permissible between supporting ribs. As a matter of fact, the thickness of the plate, the character of the applied active material and the service battery is to render, all have an important bearing, though there is no definite law on this subject, and the question is one that can only be settled by experiment.

(3) *Corrugated and Solid Recessed Plates not Perforated.* Under this heading come the Tudor, Fig. 40; the Pollak, Fig. 41, and Khotinsky, Fig. 42.

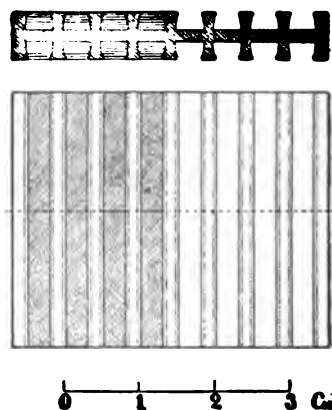


FIG. 42.

The active material is laid on both sides of the plate and pressed securely into the grooves or recesses.

A combination of the recessed and perforated groups—is the Sperry grid, shown in Fig. 43, and the Exide negative, Fig. 44.

The Sperry grid is made of a thin sheet of rolled lead having strengthening ribs around the outer edges. Small triangular holes are punched through the sheet in such a manner that the punch cuts out only two sides of the triangle, and bends the cut portion out perpendicular to the plane of the plate. The resulting grid is perforated and has numerous projecting "fins" or teeth on each side, resembling a grater. The active material is applied under heavy pressure which welds it together solidly into a cohesive mass, covering both

sides of the plate and passing through the holes. Additional hold on the active material is furnished by the bending over of the fins, which clinch themselves over the outer surface.

The Exide is similarly constructed except that the perforations are circular and the raised fins are cut radially

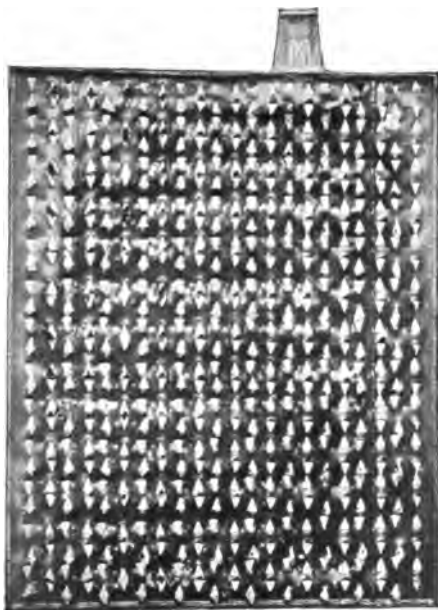


FIG. 43.

and when pushed out, stand around the periphery of the holes as shown.

(4) *Double Ribbed Plates.*

An example of this group is the Kölner Accumulatoren Werke, shown in Fig. 45.

(5) *Plates Made of Ribs having Enlarged or Projecting Portions.*

Examples of these are: Hladik, Grunewalt & Co., Fig. 46; Hobel, Fig. 47; Schulze, Fig. 48; Accumulatoren Fabrik. A. G., Fig. 49.

The projections serve the double purpose of retaining the

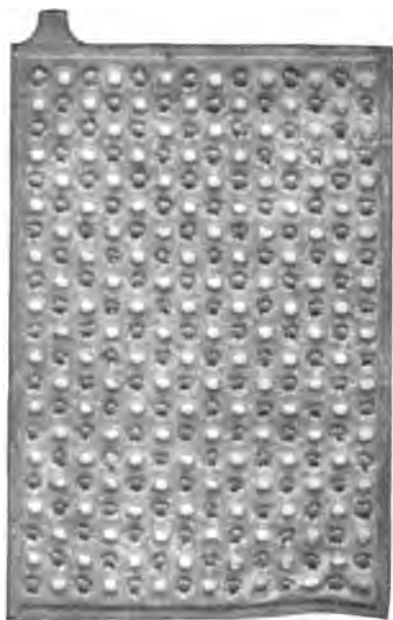


FIG. 44.

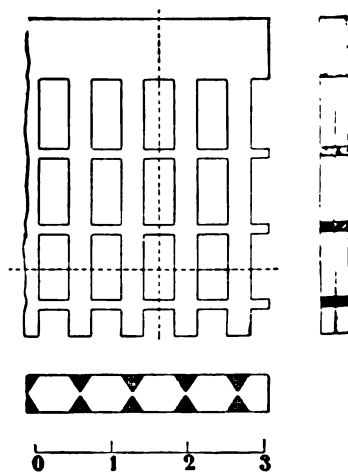


FIG. 45.

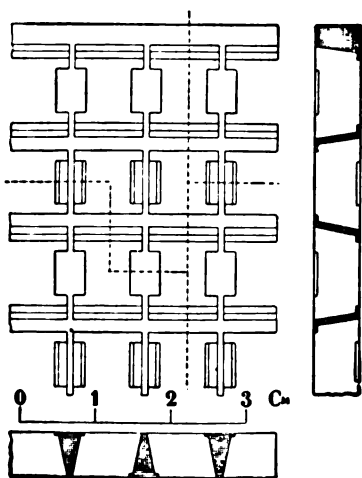


FIG. 46.



FIG. 47.

active material and affording proper contact for conductivity.

All of these grids are filled up with sufficient active material to form a flat smooth paste.

(6) *Grids having Horizontal Ribs Only.*

The Porter, Fig. 50, and Gelnhausen, Fig. 51, illustrate this style of grid. In the Porter, every space is filled with the active material, while in the Gelnhausen, certain divisions

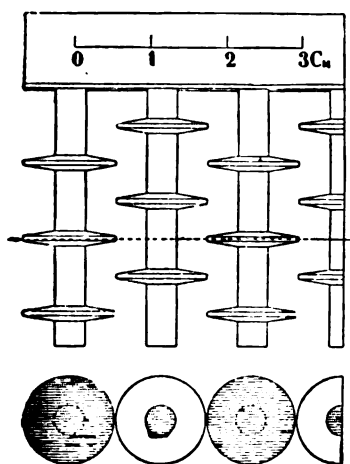


FIG. 43.

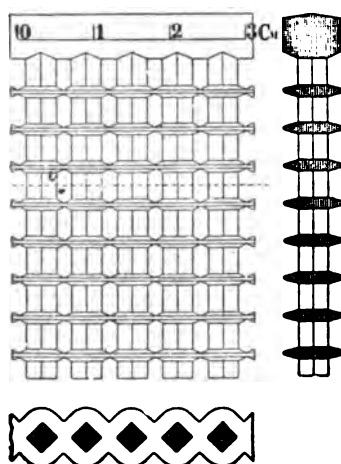


FIG. 49.

at equal intervals, measured vertically, are left unfilled, to allow expansion and contraction and circulation of electrolyte.

(B) *GRIDS CAST AROUND THE ACTIVE MATERIAL.*

In certain varieties of plates, the active material is formed into pellets, cylinders or other shapes which are laid in moulds and the lead supporting grid cast around them. Usually the casting is done under pressure to insure good mechanical and electrical contact, freedom from blowholes and elimination of impurities.

Under this group may be mentioned the Reckenzaun, Fig. 52, and the Chloride, Fig. 53.





FIG. 52.



FIG. 50.

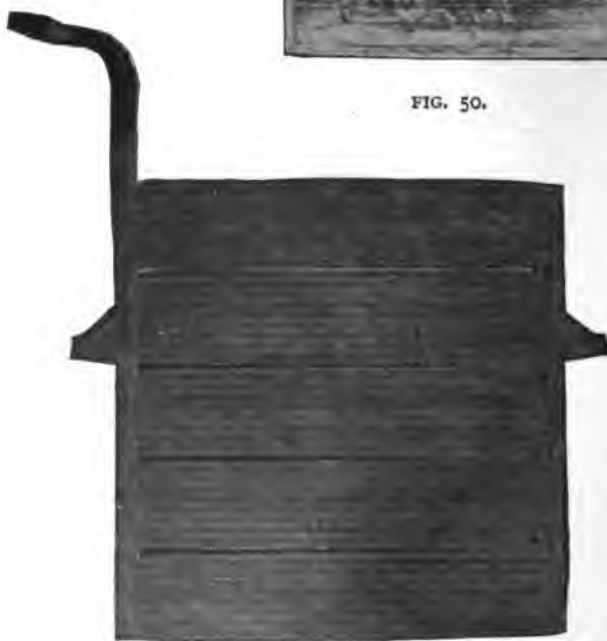


FIG. 51.

wire

## (C) LEAD ENVELOPES.

The principal exponents of this group are Tommassi, Fig. 54; Van Gestel; Johnson & Holdregge; Perret, and Ford-Washburn.

The first is a perforated tubular vessel, as shown, into



FIG. 53.

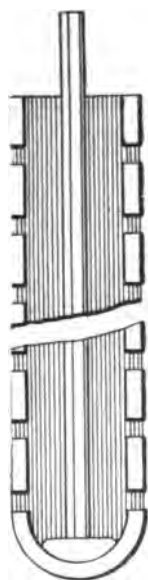


FIG. 54.

which the active material is placed. The second is a plate formed by filling a long, perforated tube with active material, and then bending it upon itself until a sufficient number of layers have been made to complete the plate.

The Johnson & Holdregge is a flat plate made up of two thin perforated sheets of lead, flat on one side and ribbed on the other. The ribbed sides are bolted together, spaced slightly apart, and in the space thus formed the active mate-

rial is pressed. Steel pins are passed through the holes before the active material is put in and removed afterwards, leaving a perforated plate and allowing circulation of electrolyte in and through the plate.

The Perret battery is not a plate accumulator, but each electrode is a single rectangular, perforated lead tube filled with active material and suspended in the cell from the top. Capacity is secured by joining a number of tubes in parallel.

The Ford-Washburn electrode consists of a flat chamber made of two thin perforated lead sheets filled with active material, in which is embedded a conducting lead strip.

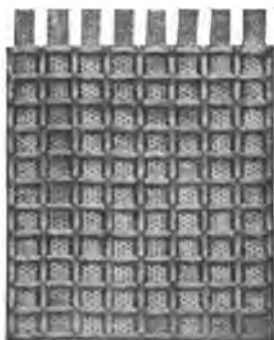


FIG. 56.



FIG. 57.

#### (D) NON-METALLIC GRIDS.

Attempts have been made to produce pasted plates with the grids made of some substance other than lead.

The majority of the designers working on these lines were looking principally toward the production of a lighter battery than has been possible with lead grids, though a few were working with the object of confining the active material so that it could not drop away from its support.

The Rooney is an example of the first. This grid is made up of hair felt with pockets on either face, as shown in Fig. 56. Running vertically through the middle of the plate and forming the bottom of each of the pockets is a thin lead strip to each vertical row of pockets. The ends of the strips pro-

ject above the top of the grid and are connected together. Fig. 57 shows the plate filled with active material, a separator being partly cut away.

The active material is pasted into the pockets and is in intimate contact with the lead strip forming the bottom of the pocket. The only action that takes place is on the active material, the strips being completely covered and acting as conductors of current only.



FIG. 58.



FIG. 59.

The Hatch battery is an example of the second type and is shown in Figs. 58, 59 and 60. Each electrode consists of two plates of unglazed, porous earthenware, having pockets or channels formed on their faces. These pockets are filled with active material in sufficient quantity to project above the face of the plates.

Two plates of earthenware with a sheet of lead between them form an element. The active material being in contact with the lead sheet, the latter is enabled to convey the current to or from the active portion. The reverse sides of the earthenware plates are also filled with active material and thus the elements are formed consecutively, each alternate element being of the same and adjacent elements being of opposite polarity. The plates making up a complete cell are held firmly together by stout rubber bands to insure

good contact between the active material and the lead plates and also to prevent the former from dropping out.

The Winkler plate, shown in Fig. 61, consists of a vertical row of triangular troughs which are filled with active material. This plate may be made of lead, or, if lightness is desired, of vulcanite, celluloid or any acid proof material possessing rigidity. In this latter case, a lead conductor is

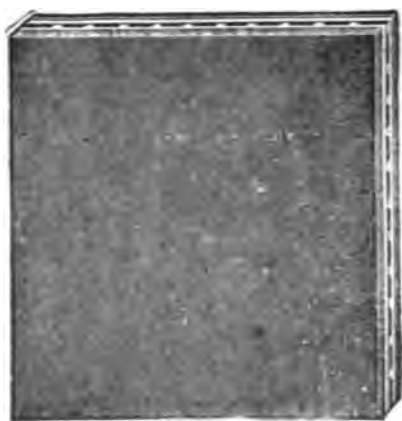


FIG. 60.



FIG. 60A.

laid in the bottom of each trough and completely surrounded by the active material.

These various types of grids, and special plates, are shown to indicate the number of forms that the pasted battery has passed through. The list here, is far from complete, as it is not intended to give a description of every grid that has been produced. To do so, would require considerable space and could be of but little interest to the practicing engineer. Indeed, many of the forms shown are not in use to-day and are set forth here only to show how fully the field has been covered.

Pure lead does not possess sufficient rigidity to make a

suitable grid where the active material is mechanically applied.

If the grid be slightly bent, the active material is likely to crack off. While this is also true of Planté plates, it is only so to a limited extent, as the active material is much thinner and usually formed on small surfaces independent of each other.

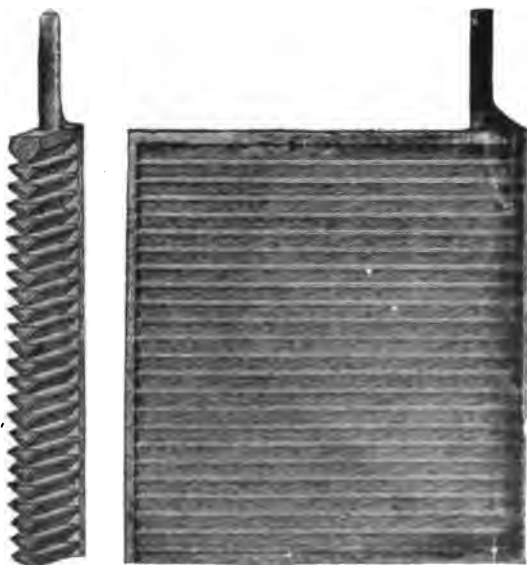


FIG. 61.

It therefore becomes necessary to mix with the lead some metal or metals which will give this needed strength and resistance against distortion, but which, at the same time, will not materially change the voltaic characteristic of the grid.

The metal most commonly used is antimony, and the proportions of the alloy vary from 88 per cent. lead and 12 per cent. antimony to 98 per cent. lead and 2 per cent. antimony by weight. The most usual mixture is 96 per cent. lead and 4 per cent. antimony.

Mercury and tin have also been used; for instance, the

composition of the Worms grid is given as 96.5 lead, 2.2 per cent. antimony and 1.3 per cent. mercury. The Julien grid is composed of 92 per cent. lead, 3.5 per cent. antimony and 4.5 per cent. mercury; the Nevens grid is composed of 23 per cent. lead and 77 per cent. tin.

It seems to be generally supposed that these alloys are not attacked by the electrochemical actions which take place, and therefore last indefinitely; this idea is, in a measure, fallacious, as neither antimony nor mercury exerts any protective influence on the lead with which it is mixed.

It is true, however, that these alloys do not become oxydized as readily as pure lead, and the disintegrating action is therefore somewhat retarded.

Antimony and lead alloys are brittle and fracture if an attempt is made to bend them.

## CHAPTER XVIII.

### APPLIED ACTIVE MATERIAL MIXTURES.

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All active materials consist primarily of pulverized lead or lead oxides (Massicot, Litharge or red lead), to which is added a liquid to form a paste and in some cases other substances are incorporated.

The substances which are mixed with the lead or lead oxides may be divided into four classes.

(1) Substances which possess the property of causing the powdered material to harden or set (*e. g.*, dilute sulphuric acid).

(2) Substances which increase the conductivity of the resulting active material (*e. g.*, pulverized carbon).

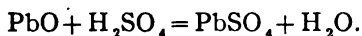
(3) Substances which increase the porosity of the active material (*e. g.*, pulverized pumice stone).

(4) Materials which are themselves inactive but which bind together the active material and retard the disintegration thereof (*e. g.*, asbestos fibre).

Of these four substances the first must always be present, with or without any or all of the other three.

It is obvious that there exists an almost infinite number of combinations which practically attain the same objects. The following are some of the most important of the mixtures in actual practical use.

The oldest of the pasted active materials is litharge mixed with sulphuric acid. Lead sulphate and water are formed when the mixture is made as shown by the equation.



It appears, therefore, that the pasting is done in reality with a mixture of PbO and lead sulphate. The acid with



which the  $\text{PbO}$  is mixed is not present in sufficient quantity to completely sulphate the mass.

The sulphuric acid used in the mixture is about 1.120 specific gravity, the proportion of liquid to litharge being 1 to 6. The mixing must be very thorough, and as little acid as possible used. The resultant mass appears as moistened, but not of such consistency that it can flow. After filling a grid, the plate is usually subjected to pressure and all the portions of the grid filled, the entire combination being tightly compacted. The plate is then dried in air. If the drying takes place at ordinary room temperature, from one to two weeks are required, according to the dryness of the air and thickness of the layer of active material. In some cases, the drying is accelerated by placing the plates in ovens and maintaining therein a temperature of about  $200^{\circ}\text{F}$ .

After being fully dried, the plates are assembled and charged, and discharged several times, after which they are ready for the market.

The active materials most commonly used are litharge ( $\text{PbO}$ ) for pasting the negative and minimum or red lead ( $\text{PbO}_2$ ) for the positive. The negatives need only to be reduced to sponge lead ( $\text{Pb}$ ) by the action of evolved hydrogen in a dilute sulphuric bath. They are connected as cathodes with "dummy" plates of sheet lead as anodes, and current passed through the group.

The  $\text{Pb}_2\text{O}_3$  on the positive plates is changed to  $\text{PbO}_2$ —( $\text{Pb}_2\text{O}_4$ ) by the addition of oxygen, which is supplied by connecting up against dummy plates, in a sulphuric acid bath, and passing current through the couple, the dummies being connected as cathodes, and the positive plates as anodes.

*Böse* makes a flat sheet of active material to fit into the grid shown in Fig. 38 by mixing the lead oxide and peroxide with alcohol, the latter having dissolved therein, some distillate of coal tar. Anthracene is given as an example of the hydro-carbon which is mixed with the alcohol.

The resulting mixture is pressed into the grid, and dried in hot air ovens, after which the plates are hardened by im-

mersing in dilute sulphuric acid. The final process is formation by charging and discharging

*Verdier* uses a paste made of litharge mixed with glycerine and water

After drying, the plates are treated in solution of sodium sulphate mixed with glycerine and water, and are finally formed.

*Desruelles* forms a paste from 60 parts red lead, 40 parts graphite, 25 parts pulverized porcelain and 10 parts white of egg. The graphite is intended to increase the conductivity and the pulverized porcelain is to give porosity. The albumen forms a good binding material.

*Metzger* makes a paste of lead oxide, dilute sulphuric acid and potassium silicate.

*James* uses the following compounds.

For the positive elements: Minium 85 per cent., litharge 10 per cent., carded asbestos 4 per cent., and powdered carbon 1 per cent.

For the negatives: Litharge 94 per cent., carded asbestos 4 per cent., sulphur 1 per cent., and powdered carbon 1 per cent.

*Sperry* makes a mixture as follows:

Seventy per cent. of sponge lead, 26 per cent. red lead and 4 per cent. of ammonium sulphate. This is slightly moistened with dilute ammonia, but not sufficiently to more than make it into a dampish powder. Powder is put into a die, the grid on this, and another layer on top, and the whole compacted in a hydraulic press.

#### LITHARGE, GLYCERINE AND SULPHURIC ACID.

Litharge, when made into a paste with sulphuric acid and glycerine, forms an excellent active material, especially for the negative plate.

In mixing, the glycerine and concentrated acid are first mixed, using equal volumes of each. The resulting liquid becomes heated by reason of the chemical combination which takes place. After cooling, water is added in such quantity that it forms about 66 per cent. of the total volume

of the liquid. The litharge is made into a stiff paste with this mixture, the proportion being about 870 cu.cms. of liquid to 4 kilos of litharge.

In applying this plate to the grid, it is usual to apply pressure by passing the pasted grid through rubber rolls which press out a portion of the moisture.

It is stated that when formed into negative plates this material produces a tenacious, felt-like lead sponge far superior to the brittle, granular lead sponge formed from the simple litharge and sulphuric acid paste.

#### RED LEAD WITH GLYCERINE AND SULPHURIC ACID.

This mixture and method of application is the same as the case just preceding, except that minium is substituted for litharge and less liquid is required to form a paste, the proportion being about 625 cu.cm. of liquid to 4 kilos of minium.

#### PULVERIZED LEAD AND WATER.

A mixture of lead dust and water forms a good active material which sets like a cement and becomes hard and dense. The lead dust must be carefully handled and all air excluded from it.

The density of this mixture is rather too high to allow of porosity, and manufacturers who use this form of active material usually add crushed pumice stone, or some equivalent substance, to the mixture to correct this defect.

#### LITHARGE MIXED WITH CAUSTIC SOLUTIONS.

If litharge be mixed with a saturated caustic solution, such as potassium or sodium hydrate, the resulting paste will harden or set within a minute, at ordinary room temperatures, and so quickly does it harden that such a mixture cannot be worked.

If, however, the solution be diluted, the time required to harden increases proportionally to the degree of dilution and by reducing the strength of the solution the material can be handled and applied to the grid before it sets.

A proportion of one part of salt crystals (sodium or potas-

sium) to two or three of distilled water, by weight, is stated to be a satisfactory mixing solution.

*Fitz-Gerald* has devised three mixtures which he terms "Lithanode" Nos. 1, 2 and 3.

No. 1 consists of litharge mixed with solution of sulphate of ammonia to form a paste, or the two salts mixed together and afterwards made into a paste with water. The grids pasted with this mixture are "seasoned"—presumably exposed to the air—for some time, varying with the thickness of the active material. After the seasoning, the plates are painted with peroxide of lead in fine powder to render them conductive, and then connected as anodes to form positives, and as cathodes to form negatives, in a solution of sulphate of magnesia. The resulting plates are porous and have high conductivity.

Lithanode No. 2 consists of litharge mixed with sulphate of lead. This mixture hardens and sets firmly and is not affected by acid or water.

Lithanode No. 3 consists of litharge mixed with a solution of caustic potash.

*Marchenay*.—The material invented by A. Marcheney, of Paris, and known as the chloride pellet or active material, belongs to the class in which the connection with the conducting support is obtained by casting the grid around pellets of the material which had been previously introduced into the moulds and shown in Fig. 53.

Lead Chloride is made by dissolving finely divided metallic lead in dilute nitric acid, from which it is precipitated in the form of chloride of lead by adding hydrochloric acid. It may also be obtained by dissolving litharge in acetic acid and precipitating with hydrochloric acid.

The lead chloride is washed and then fused with zinc chloride and the resulting molten mixture is poured into moulds in the form of square pellets, three-quarters inch on a side and five-sixteenths inch thick. These pellets are placed in position in the grid moulds and the grid cast around them under pressure.

The plates are then assembled with zinc plates in a solution

of zinc chloride and short circuited. This causes the removal of most of the chloride.

The plates are washed in running water to free them from the last traces of chloride. The active pellets are left in a spongy condition and may be formed into positives or negatives as desired, though in practice, they are used exclusively as negatives.

In many instances, the formation of applied active materials requires as long a time to carry through as the improved Planté formations, as the red lead and litharge must be brought to the condition of  $\text{PbO}_2$  and Pb respectively, by the liberation of oxygen and hydrogen.

Consider, for instance, a forming cell containing 20 negative plates, each being pasted with one-quarter kilogram of litharge—a total of 5 kilos of litharge to be reduced.

Taking the atomic weights (gramme equivalents) of the various combinations:

1 Molecule of litharge ( $\text{PbO}$ ) weighs  $206.5 + 16 = 222.5$  g.

1 Molecule Hydrogen  $\text{H}_2 = 2$  g; must combine therewith to form water.

1 Molecule  $\text{H}_2\text{O} = 2 + 16 = 18$  g.

1 Atom lead ( $\text{Pb}$ ) = 206.5 g.

One ampere hour will release 0.0374 g. of hydrogen.

One Kilo of litharge requires 8.97 g. of hydrogen to reduce the oxygen to water and 5 kilos require 44.85 g. of hydrogen

$$\frac{44.85}{0.0374} = 1200 \text{ ampere hours}$$

required to reduce litharge to Pb. Since the rate of current flow through the plates must be limited to a certain density per square inch—varying with the type of plate, but usually about 6 amperes per square foot, both sides of each plate being considered—these plates would be formed with about 15 amperes flowing, this being about the proper current for plates of such a size as to have pasted thereon 5 kilos total of active material of usual thickness.

$$\frac{1200}{15} = 86.7 \text{ hours required for theoretical reduction of the PbO to Pb.}$$

In practice, from 20 to 30 per cent. more electrical energy

is required than the theoretical, owing to imperfect penetration and escape of gases which do not assist in the reduction of the oxide, but escape into the air.

Considering the positive plate; take as an example 20 plates, as before, in a forming tank, each being coated with one-quarter kilo of red lead or minium, giving a total of 5 kilos on the 20 plates

$$1 \text{ Molecule of minium (Pb}_3\text{O}_4) = (3 \times 206.5) + (4 \times 16) = 683.5 \text{ g.}$$

Two molecules of oxygen must be added to produce  $\text{PbO}_2$  ( $=\text{Pb}_2\text{O}_3$ ) and the weight therefore  $= 683.5 + (2 \times 16) = 715.5 \text{ g.}$

One gram of minium requires  $\frac{32}{683.5} = .04682 \text{ g. of oxygen to change it to PbO}_2$  and 5 kilos would therefore require 234.1 g. of oxygen. Since 0.298 g. of oxygen is released per ampere hour, the total ampere hours required to form these positive plates  $= \frac{234.1}{0.298} = 787 \text{ ampere hours.}$

Assuming, as before, a current flow of 15 amperes, the time theoretically required for formation would be:

$$\frac{787}{15} = 52\frac{1}{2} \text{ hours.}$$

At least 25 per cent. more energy, and therefore time, would be required in practice.

## CHAPTER XIX.

### ENVELOPES AND SEPARATORS.

---

In order to prevent the active material from shedding or loosening from the grid, envelopes are used on the plates whenever they are of the pasted variety. In case particles of active material should loosen or fall off they could never leave contact nor could they distribute themselves over the bottom of the containing cell, and ultimately form a short circuit between adjacent plates.

In most instances it is necessary to use them only on the positives, though in some cases the negative plates are also covered.

Faure's original patent, dated January 11, 1881, mentions retaining coverings of "Felt, Asbestos or other sufficiently porous material," for the purpose of holding the active material in contact with the grid. His early plates were covered with parchment paper and a second covering of stout felt. Neither one of these materials is now used, as the parchment paper lacks durability and the felt is expensive and not sufficiently porous.

Soft rubber, in perforated sheets, has been tried, but this is not suitable owing to the fact that it rapidly disintegrates in the action of oxygen, hydrogen and acid. In this connection, it may be here stated that soft, vulcanized rubber, in any form, soon becomes worthless if submerged in the electrolyte and should, under no circumstances, be used for permanent work.

The envelopes which have been found successful are: hard rubber, celluloid, asbestos cloth, glass wool and peroxylin. Hard rubber, in thin perforated sheets, made in the form of a case into which the plate can be slipped, makes an efficient and durable covering. It is, however, expensive and is not used much except in certain types of traction batteries.

Celluloid envelopes, made in the same way as the hard rubber ones, are also efficient, although this material decomposes somewhat under the action of the electrolyte and evolved gases. Being submerged, its inflammability is not objectionable.

Glass wool, which is glass in a finely divided fibrous state, is sometimes used. It is packed into the spaces between the plates and serves its purpose admirably. The mass is sufficiently porous to absorb enough electrolyte for the operation of traction batteries and also to allow of circulation.

Peroxylin is used to a much greater extent than any of the other materials mentioned. This covering is made of open mesh cotton cloth, which is chemically treated with a mixture of nitric and sulphuric acids in equal parts diluted with 2 parts water. The compound formed is of the same general character as gun cotton, and burns so rapidly as to be practically explosive. A small quantity of nitro benzol is added and the peroxylin is thereby rendered inert. It is finally thoroughly washed and then wrapped around the positive plates. After undergoing the chemical treatment, it still retains its original appearance and texture. This material is not a successful covering, however, for the negative plate, as the action of the hydrogen soon disintegrates it.

Separators are used in all batteries, being placed between adjacent plates, with the exception of those in which the plates are covered with hard rubber or celluloid envelopes. They should be as thin as is consistent with strength, and plentifully perforated, to allow thorough circulation of the acid.\*

Hard rubber, wood and glass are the materials generally used.

Hard rubber is used on smaller sizes of cells, particularly those intended for traction work. They are generally made of a thin sheet of perforated hard rubber, strengthened at intervals by ribs. The differences in the hard rubber separators manufactured by the various companies, lie almost entirely in the disposition and form of these ribs.

A large number of small perforations is preferable to a smaller number of large perforations as, obviously,



there is less opportunity for the particles of active material to pass through the smaller holes.

Wood separators are frequently used in both large and small batteries. They seem to be satisfactory and efficient, but there is always danger that acetic acid may be released from them and injure the plates. One of the American companies uses them extensively, but they are generally considered detrimental to the life and efficiency of a cell.

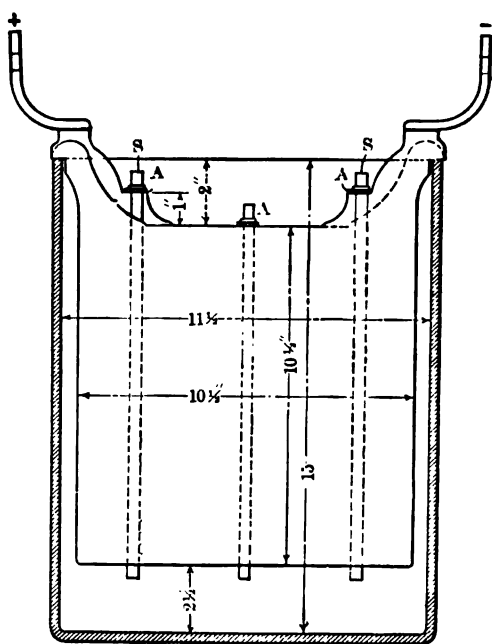


FIG. 62.

and are unquestionably to be avoided except when an old battery begins to shed its active material rapidly, and the question becomes one of positive surface separation and prevention of internal short circuits.

Glass separators are used almost exclusively in large cells. They are merely glass rods, varying in diameter from three-sixteenths of an inch to five-eighths of an inch, with a flange or ring near one end. These rods are placed between the

plates extending vertically from top to bottom, and they are held in position both by the plates on either side and a strip of rubber through which the rods pass.

Referring to Figs. 62, 63 and 64, s,s,s, are the glass rods,

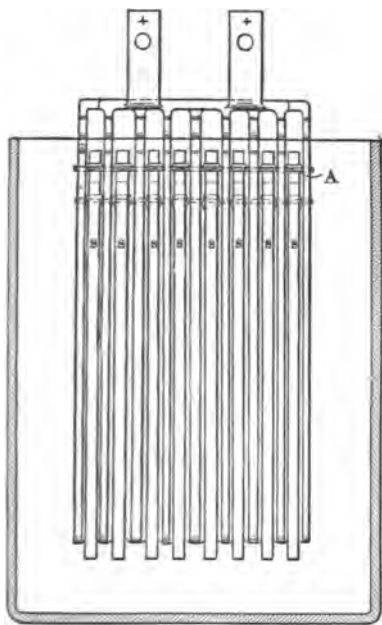


FIG. 63.

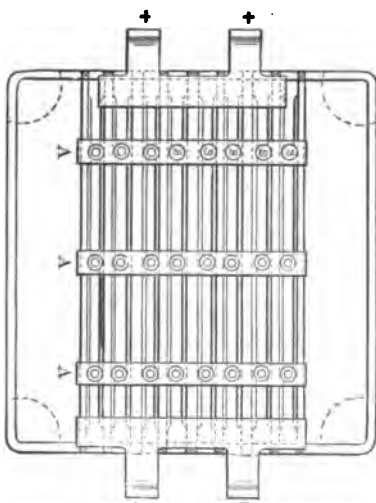


FIG. 64.

and A.A.A., the rubber strips which lie across the tops of the plates, and through which the glass rods pass. The latter cannot drop through the holes in the rubber, as the flanges at the upper end serve as stops.

The rubber strips may be either hard or soft; both are used in practice.

## CHAPTER XX.

### CONTAINING CELLS.

---

Containing cells are made of hard rubber, glass, celluloid and, in the case of the larger sizes of power station batteries, lead lined wooden tanks are used.

The hard rubber jars are used almost exclusively for traction and portable cells. The thickness of the rubber varies from one-sixteenth to one-eighth of an inch. Hard rubber makes probably the best containing cell known for small sizes of elements, the only objection being its cost.

Celluloid makes an excellent containing cell, but owing to its inflammability, and consequent liability to take fire and burn with almost explosive rapidity, is used but little. A carelessly lighted match, or an electric spark—which latter is often made in changing connections at battery terminals—in proximity to a cell containing celluloid, would constitute a source of danger.

This material is used more in Europe and England than in America, it practically being used not at all in this country.

Glass containing cells are suitable only for stationary batteries. They are thoroughly satisfactory in every respect after once being installed, and are cheaper than any other kind.

Sir David Salomons has observed that if glass cells are exposed to light they sometimes crack, owing to unequal expansion.

Unfortunately, it is practically commercially impossible to make these cells in large sizes, the limiting dimensions being about 12 x 12 x 15 inches.

For large size station batteries, heavy wooden tanks, lined with sheet lead, are used. The lining is generally of from 4 to 6 pound lead, according to the size of the tank, that is, of such thickness that 1 square foot weighs from 4

to 6 pounds. The lead lining should be turned over the top edges of the tank and cover them.

The tanks themselves should be made of sound oak or teak wood thoroughly dried and boiled in paraffine or some

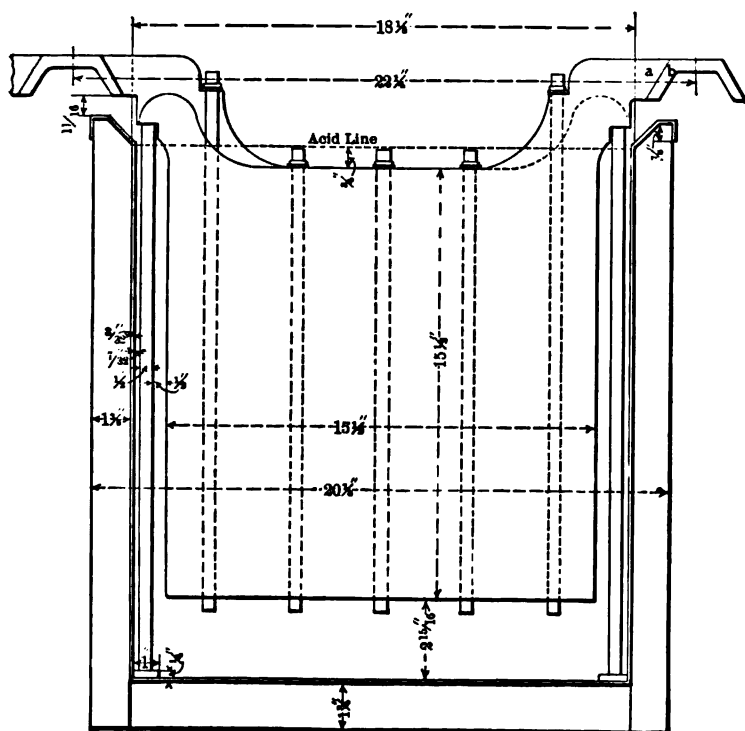


FIG. 65.

equivalent compound, so that the pores are completely filled and there can be no absorption of spilled or leaking acid.

The parts of the tank should be dove-tailed together, and the whole strongly assembled.

When lead lined tanks are used, the elements are always suspended by lugs which usually are cast or burned onto the tops of the plates. These lugs rest upon glass sheets on either side of the tank which project above the upper edges

of the tank. Since the entire weight of the elements comes on these glass supports, a reinforcing strip of lead must be placed underneath them in the bottom of the tank, otherwise they would probably cut through the thin lead lining. The glass sheets are from one-eighth to five sixteenths of an inch in thickness depending on the size of the cell.

Fig. 65 shows the dimensions of a lead lined tank for elements  $15\frac{1}{2} \times 15\frac{1}{2}$ . The glass supports are seen on either side, and come within seven-thirty-seconds inch of the lead lining. The reinforcing strip of lead at the bottom of the glass sheets, is one inch wide by one-quarter inch thick. The glass separators are also shown.

It is customary to bore a hole through the wooden bottom of the tank so that any leak in the lead lining will manifest itself at once.

The Gould Storage Battery Co. experimented with glazed earthenware jars as containing cells for the larger sizes of station batteries, and for a long while they proved thoroughly satisfactory, but it was discovered, after one and a half years of use, that the inner glazed surface became so changed the electrolyte was able to penetrate through it and a gradual, but continuous, leakage of electrolyte began to take place. This type of containing cell has therefore been abandoned.

In computing the size of a tank required for a given number of plates of specified dimensions, it is necessary to know the effective volume of the plates, of the envelopes (if any are used) and separators. Also the volume of the electrolyte.

It is practically impossible to compute the first three volumes owing to the fact that there are so many minute pores which cannot be estimated. The author prefers to immerse several plates (both positive and negative), and separators in a vessel of given dimensions partially filled with water, and observe the rise in the height of the surface of the water, after the expiration of say half an hour and from this deduce the volumes required. This, added to the volume of the electrolyte, which latter is computed after the weight and density which have been fixed on, gives the volume of the tank. There is one dimension only of the

tank, which is fixed, and that is the width, which cannot be varied to any extent, especially in cases where the plates hang from the top of the cells, being supported by lead lugs which rest on the upper edges of the glass lining which project above the edges of the cell. The inner width, therefore, can vary but little more than the width of the plates plus a small amount of clearance.

The depth and length can be varied as desired to produce the given volume. It is desirable that the depth of the tank should be as small as possible, as the denser electrolyte formed during charge, tends to sink to the bottom of cell and in deep tanks, say 20 inches and above, it has been found that the electrolyte density in the top and bottom of the cell differed considerably, with the result that the electrical and chemical actions also differed, producing an inequality of current distribution over the surface of the plate, a higher E.M.F. at the bottom than at the top of the plates, and in some instances this difference of E.M.F. has combined with the small differences which sometimes exist in the active material in the same plate, to set up local action.

If the volume be made up by increasing the length, the plates should not be separated any further from each other in order to distribute them along the length of the tank. they should be brought together as close as is compatible with safety from short circuits, from scaling of active material or buckling, and in case the length be made greater than actually required to contain the plates, the difference should appear as an open space at either end of the tank. This, however, is seldom necessary as the top, bottom and side spaces, together with the spaces between plates, usually give ample room for the amount of electrolyte required.

## CHAPTER XXI.

### ASSEMBLING AND INSTALLING.

---

In assembling plates together, joining the edges of the lead linings in tanks, or making any lead joint or connection, the two pieces to be joined should always be flowed or "burned" together. This operation consists in subjecting the edges to be united to a high temperature, such that the lead is melted and flows together, forming in effect a lead weld.

This is accomplished in practice by means of the oxy-hydrogen blow pipe, which is merely a small copper or brass tube of about three-sixteenths of an inch outside diameter and one-eighth of an inch bore. One end is capped with a small nozzle of from one-sixty-fourth to one-thirty-second of an inch opening, the other end being covered with wire gauze. The tube is usually bent near the nozzle end to about a 30 degree angle, to facilitate the application of the flame on different forms of work. The end which is covered with wire gauze is inserted into a rubber tube, which leads the mixed oxygen and hydrogen gases to the blow pipe. The gauze is to prevent the flame at the nozzle from running back to the gas reservoirs. A stopcock in the line of the rubber tube permits the adjustment of the strength of the flame.

The rubber tube goes from the nozzle to a branch where two rubber tubes lead in; one connecting with the hydrogen, the other with the oxygen or air reservoir. Stopcocks are also inserted in each of the branch tubes, so that the mixture can be varied. The rubber tubes are about one-quarter of an inch inside diameter.

Hydrogen is generated by the action of sulphuric acid on zinc. The apparatus for producing this gas is shown in Fig. 66.

A and B are air-tight tanks, A being about 4 feet above B.

A lead pipe, *c*, runs from the bottom of A into B, and on down, nearly to the bottom of B. *d* is a perforated partition or false bottom in B, on which scraps and small pieces of zinc are placed, entrance being effected through the tight-closing opening *f*. Sulphuric acid is poured into B, and the

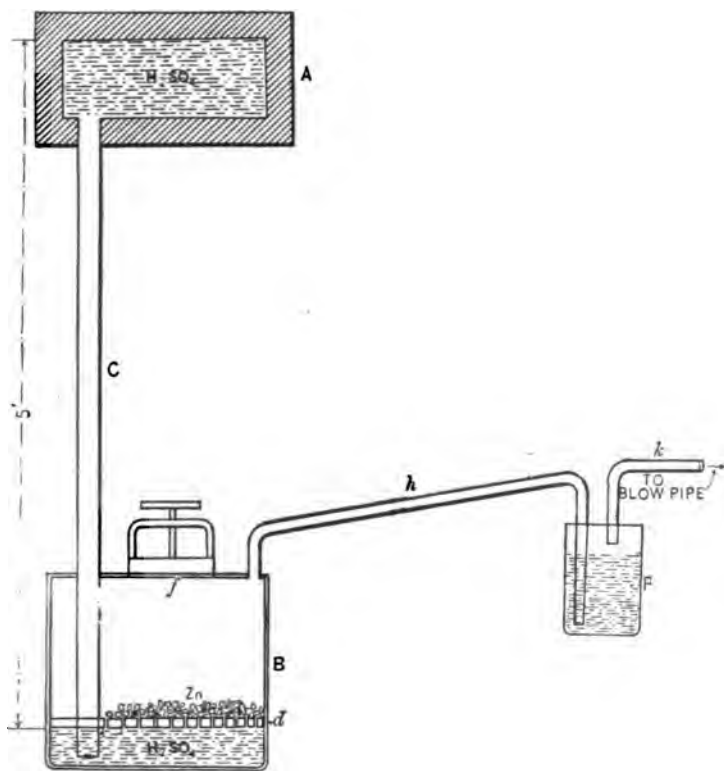


FIG. 66.

opening, *f*, closed up. Hydrogen is liberated and pressure generated in B, which, on reaching a certain value, forces the acid out through *c*, up to tank A, leaving the zinc uncovered, and the generation of gas ceases. If any be withdrawn through *h*, the pressure in B will fall, some acid will flow down from A and cover the zinc, resulting in the liberation of more gas. Thus the generator is entirely automatic, and



the pressure is always constant, being equal to the pressure due to a column of water of a height equal to the difference between the levels of the liquid in the two tanks, multiplied by the specific gravity of the liquid. The usual pressure is about three pounds per square inch.

From the generator the gas passes through *h* to *P*, which is a vessel filled with water, through which the gas must all pass before going through *K* to the blow pipe. *P* serves both

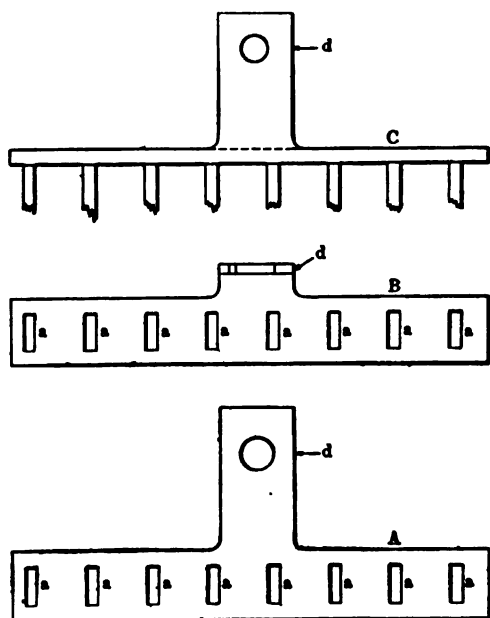


FIG. 67.

to purify the gas and also to prevent the flame from getting back from the blowpipe to the generator. The oxygen is supplied by pumping air into a reservoir or tank, a small, automatically controlled pump being used.

The electric arc has been suggested for lead burning, and at one time the author made some investigations in this direction, but found that the work, though satisfactory, was not so good as could be done with the oxy-hydrogen flame, as the heat was too much localized. The chief difficulty

with the arc, however, and one that makes it wholly impracticable, is the effect on the eyes of the workman. Smoked glasses and shields of all kinds were tried, but after a few operations the operator had to stop and for several minutes was practically blind from the dazzling light, though

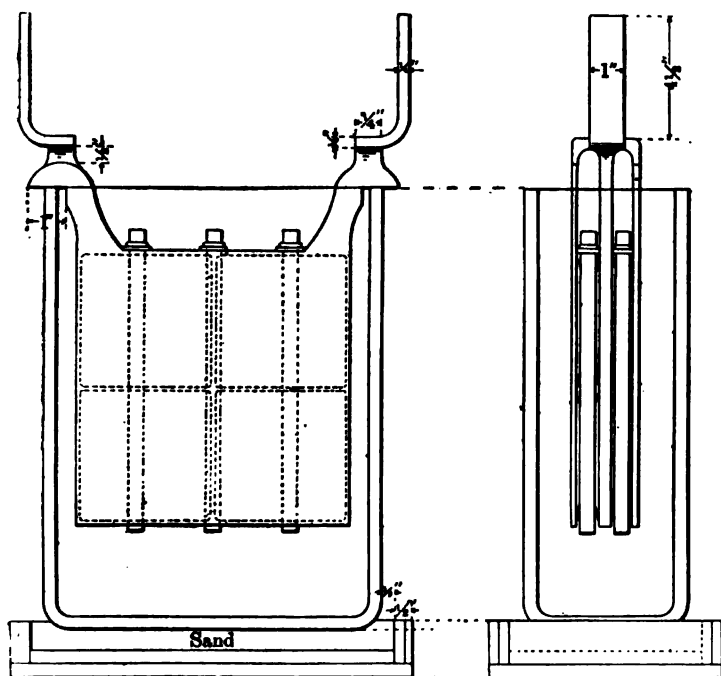


FIG. 68.

the effect soon passed off. The use of the arc was therefore abandoned.

In cases where the amount of work done is small, the lead joints can be made by soldering. In large installations, however, the construction is carried on with the assistance of a portable oxy-hydrogen apparatus.

The individual battery plates are assembled together to form a complete cell, by "burning" to a common lead bar or strip, all the plates of like polarity; there being, of course,

two bars for each cell, one being joined to the positive, and the other to the negative plates.

The usual practice in the small and moderate sizes of cells, is to make the plate connectors in the form shown in Fig. 67.

A is a plan of the connector which is cut out of sheet lead in the form shown. The rectangular holes, a, a, a, a, are the size of the lugs on the battery plates, and are spaced the distance apart that the plates of one polarity are to be.

The projecting end, d, is turned up at right angles to the plane of the connecting strip as indicated in B and C. At C

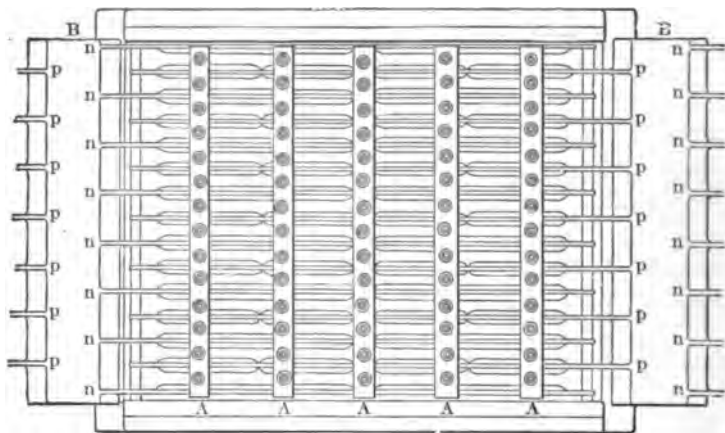


FIG. 69.

is shown the ends of the plate lugs inserted into the holes. The plate lugs and strip are burned solidly together, and then constitute a complete element. A positive and negative element are put into a cell, the plates being properly spaced by the connecting strips and adjacent plates prevented from touching by some form of separator. The cells are joined together by burning the ends dd, dd, together, or by bolts. Fig. 68 shows a small, three-plate cell with strap connectors.

If the cells be moderately large—say of 350 ampere hours capacity and above—two joining straps may be required in order to give sufficient current carrying capacity.

When bolt connectors are used, the nuts are made of hard

brass or iron, and covered with lead. The studs are of iron or brass, but not lead covered, being protected by the nuts on either end, and the straps through which they pass.

It may here be noted that all metal work near batteries

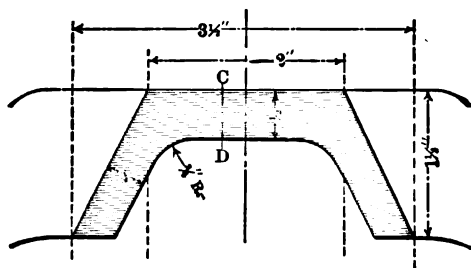


FIG. 70.

must be lead covered. Any metal in a battery room subjected to acid fumes, should be painted with acid proof paint. When connections are made with bolts, they should be inspected every month for the first two or three months, as the soft lead of the straps and nuts tends to "flow" under pressure, and joints that have been made tight, occasionally, flatten out and loosen after a time.

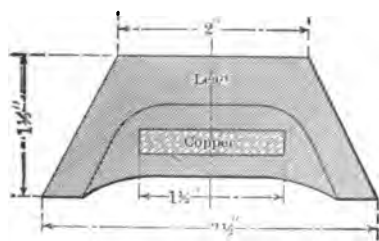


FIG. 71.

In larger size cells, strap connectors and assembled elements are too heavy to be handled, and the assembling is done as shown in Figs. 65, 69 and 70. In Fig. 69, is shown a plan of the cell arrangement and connections. p, p, p, p, are positive and n, n, n, n, negative plates; b, b, b are lead bus bars of section as indicated in Fig. 70. As is seen in Fig. 65, the connecting lugs of the plates extend over the

edge of the cell, and are bevelled to rest against the side of the bus bar. The tanks are first put in place, then the plates put in and spaced by the glass separators, after which the

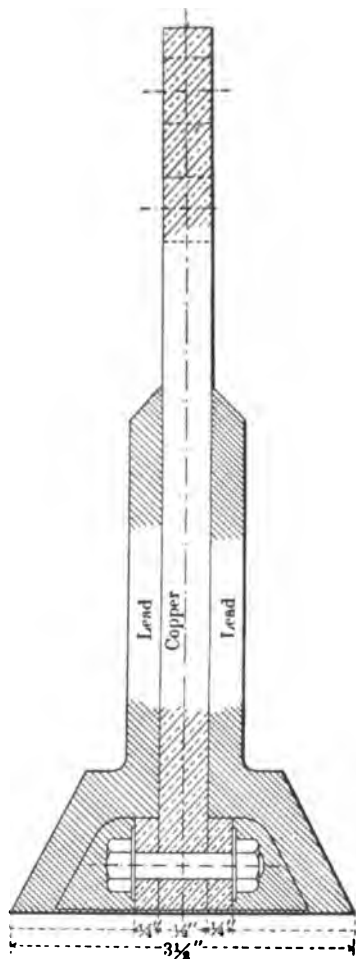


FIG. 72.

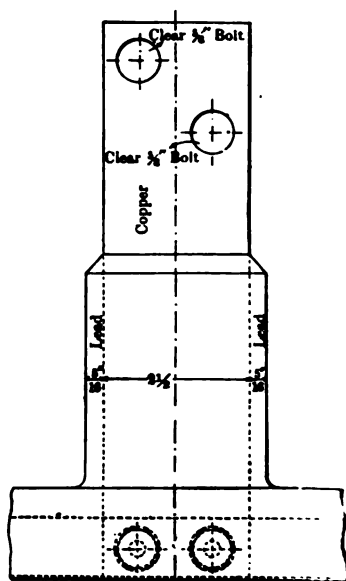


FIG. 73.

bus bars are put into position, and the lugs burned solidly to the bars. The cells are thus joined in series, and the path travelled by the current from one cell to next, is very short.

Indeed, some makers have installed cells in which the tanks were placed close together, and each positive of one set of elements was joined directly to a negative of the adjacent set.

The cross section of the bus bars need not be great, as the distance that the current is carried is short, and the path

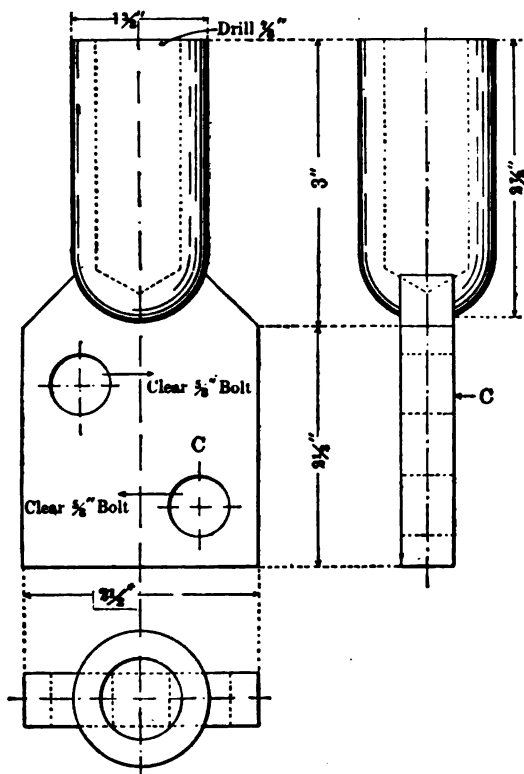


FIG. 74

is practically from plate to plate. Also, since conduction takes place *across* the bus bar from side to side, instead of *along* its length, the cross section available for conduction per plate is C, D (Fig. 70), multiplied by the length of the bar from the centre of one plate to the centre of the next.

When the last cell is reached and the current is led to the switchboard, it must travel, at least for a short distance,

along the length of the last bus bar, and in order to give it proper carrying capacity it is reinforced, as shown in Fig. 71. A copper strip is laid in the channel on the under side of the bar, and lead poured around it, the conductivity being increased thereby. In some cases, the copper bar is put into a mould, and the lead poured directly around it.

At points where the current is taken off, connection is made with a reinforced bus bar, by means of a lead covered

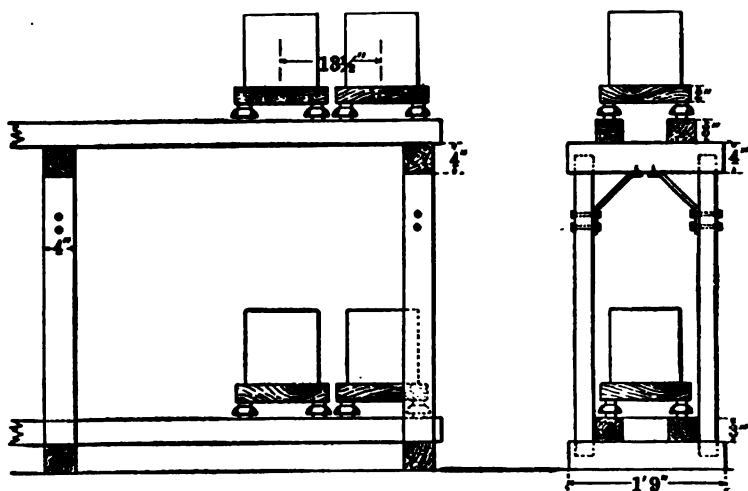


FIG. 75.

copper connector, which is joined to the copper reinforcing bar.

Figs. 72, 73 and 74 show one of the methods of making this connection. The cable terminal (Fig. 74), is bolted to the upright copper bar or connector. In many cases the upright piece is cast solid with the reinforcing copper bar, and the joining of the two obviated.

The room in which a storage battery is installed should be kept always at a moderate temperature, well ventilated, easily accessible, and the floor covered with brick or asphalt. Cement floors are not suitable, as the action of sulphuric acid on even the best of cements is to dissolve them, and make them mushy and cause their final disintegration.

Asphalt makes the best floor, and when laid over brick, concrete or cement, in a thin layer—say three-quarters of an inch thick—is not expensive. A very clean, but expensive, floor is made of vitrified brick or tiles, laid together, and in

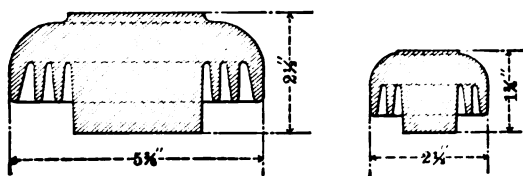


FIG. 76.

cement. After the cement gets nearly set, the top of the joints between adjacent bricks or tiles is scraped out, and the interstices thus made filled with hot asphalt.

It should be noted that only the best quality of asphalt, free from tar and pitch adulteration, is permanent and satisfactory. If wooden floors are used, catch troughs of thin lead should be placed under each row of cells.

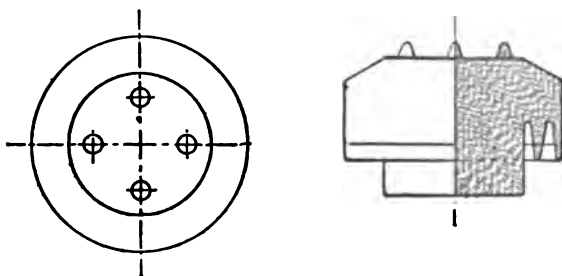


FIG. 77.

The battery room should always be generously ventilated, the path from the room to the outside air being at all times unobstructed. A small electric fan placed in the ventilating opening, will serve to keep the air moving. All pipes or conduits to carry gases out from the battery room should be of acid, or acid fume proof material. Wood makes a very good conduit, as does sheet iron heavily painted with asphalt. The discharged gases should not come in contact



with any iron or steel work, as it would be corroded. Cast iron, however, is unaffected by acid fumes—probably because of the coating of silica and carbon.

Proper arrangements should be made for draining the battery room. Usually the floor is made to slope slightly from every direction downwards to a central point, at which an opening is made, connecting with a drain or sewer, the hole being covered with a cast iron grating.

Racks are heavy wooden frames or stands, on which the batteries rest, and are generally made to carry two tiers of cells, an upper and lower.

Fig. 75 shows a general form of construction which is strong and simple. The dimensions, of course, vary with the size of the cells. The method of making up this stand, and the general proportions are obvious from the figure. In laying out a battery stand, it must be remembered that the weights supported are great, and the construction must be in accordance with this fact.

Iron braces are sometimes used, but it is not advisable to do this, as the acid leaking, or being thrown out with the ebullition of gas, from the upper cells, will spread over the rack, and if it touches the iron will dissolve some of it, and probably drip down into the cells beneath, or the gases from the lower cells would corrode the iron, making loose scales, which in time would fall into the lower cells. For these reasons iron racks are never used.

If any iron is used in the construction, it should be heavily coated with asphalt, or some equivalent protective covering.

Individual cells must be well insulated to prevent leakage losses, and, as the electrolyte often spatters out when the batteries are gassing, and is a good conductor, it is difficult to maintain a high degree of insulation.

The ordinary method is to rest each cell on four triple petticoat insulators—one at each corner. Figs. 76 and 77 show the types of insulators generally used.

To prevent the spread of electrolyte, which may have leaked or spattered out, and also to give an even distribution of the cell weight over the bottom of the jar, sand trays are used with glass containing cells. These are shallow boxes



FIG. 78.

or trays made of well seasoned and paraffined wood, dovetailed and screwed together. They are about  $1\frac{1}{2}$  inches deep, and are filled with sand, and on this sand is placed the cell. The insulators are placed under the sand tray. The bedding of sand absorbs the lost electrolyte, and prevents the electrical leakage which otherwise would occur. In Fig. 68 is shown the sand tray underneath the glass jar. Trays are not used with lead lined tanks, these being placed directly on the racks or floor, with the insulators only underneath them.

Fig. 78 is a photograph of a small installation, showing battery stands, bolted connectors, which are double in this case, insulators, and sand trays. The cells are so grouped that each one is accessible for testing or inspection.

## CHAPTER XXII.

### TESTING.

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In making storage battery tests, the following should be determined:

- (1) Weight of complete cell.
- (2) Weight of elements.
- (3) Weight of electrolyte.
- (4) Dimensions of cell.
- (5) Dimensions of elements.
- (6) Normal and maximum charging rates.
- (7) Normal and maximum discharging rates.
- (8) Capacity at low, normal and rapid discharge rates.
- (9) Variation of capacity with temperature.
- (10) Variation of voltage with temperature.
- (11) Internal ohmic resistance.
- (12) Internal virtual resistance.
- (13) Specific gravity variation of electrolyte.
- (14) Loss of charge by leakage and local action.

These are all found by observation, and from these the following results are deduced:

- (15) Charge and discharge rates per square foot of positive plate surface.
- (16) Charge and discharge rates per pound of element.
- (17) Charge and discharge rates per pound of complete cell.
- (18) Capacity per pound of complete cell.
- (19) Capacity per pound of element.
- (20) Temperature co-efficients of cell.
- (21) Curves of charge and discharge.
- (22) Efficiencies at various charge and discharge rates and temperatures.

- (23) Relation of electrolyte density to ampere hours discharged.
- (24) From all of foregoing deduce the commercial value of the cell under test, and determine whether or not its characteristics are suitable for the service that it is intended to perform. If so, then test the,
- (25) Durability. This is made last because of the long time required, and should not be undertaken until all the other points are settled.

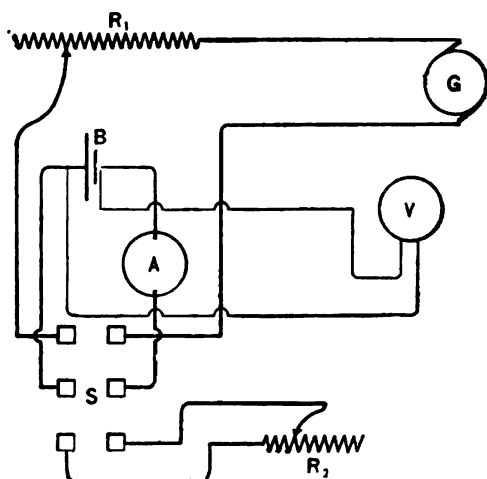


FIG. 79.

These various tests will now be considered in detail:

- (1) Weight of cell is found in the usual way.
- (2) Weight of elements is found by partly discharging, say one-fifth capacity, after giving a full charge to reduce all sulphate, removing from electrolyte and then drying with blotting paper, after which they are weighed. Do not keep the negative plates out of the liquid any longer than necessary.
- (3) Weight of electrolyte is = (1) — (2) — (weight of jar).
- (4) and (5) are determined by ordinary measurement, the elements being measured when taken out of the cell to be weighed. (4) should include all dimensions of separators, height of lower edge of plates above bottom of jar, clearance

between plates and sides and ends of jar, height of edge of jar above tops of plates; (5) should include area of plate surfaces, areas of conducting portions of the grid, area of lugs—these two last to determine if the current densities are within the limits of good practice—125 to 150 amperes per square inch. After determining (1) to (5) inclusive, connect up the battery for making the other tests. The usual way of connecting is shown in Fig. 79.

G is the constant potential source of charging current.

$R_1$  a variable resistance in series therewith.

B, the test cell; A, a two-way reading ampere meter; V, a low reading voltmeter; S a double pole, double throw switch

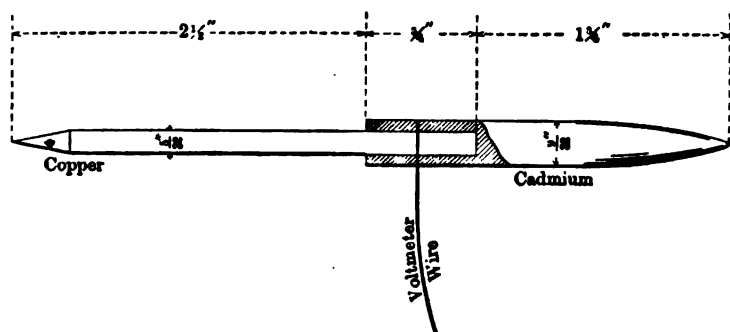


FIG. 80.

and  $R_2$  a variable resistance connecting the two lower terminals of the switch together.

By means of  $R_1$  the charging current, which flows into the battery when S is in its upper position, can be regulated. On discharge, the switch is thrown to its lower position, and by means of  $R_2$  the current outflow may be given any value desired.

The voltmeter V should be permanently connected across the battery terminals, and cadmium readings made with a separate instrument. If only one voltmeter is to be had, however, readings may be taken at intervals by placing the contacts against the lead lugs of the battery plates. The contacts should be bright and sharp, and pushed strongly against the lead lugs so that good contact is made.

A good arrangement for taking cadmium readings is to make both the voltmeter contact pieces, as shown in Fig. 80. A short piece of hard copper wire about five-thirty seconds of an inch in diameter is screwed or pushed into a piece of cadmium about nine thirty-seconds of an inch in diameter. The lead to the voltmeter is fastened about the middle point. The device is improved if it be taped about two inches along its length on either side of the point where the voltmeter lead is joined on, and it is also well to cover the cadmium completely with a rubber tube perforated with small holes. If two pieces of cadmium cannot be obtained, one piece will serve, but in this case the voltmeter connections will have to be reversed to take the negative plate readings when the battery is charging. With the two, composite, contact pieces, the voltage across the cell is read by pressing the two copper ends against the positive and negative lugs. The cadmium reading to positive is then made by taking away the contact at the negative plate and immersing the cadmium portion in the electrolyte, care being taken that it does not touch any plates or connections. If the cell be *discharging* the negative reading to the cadmium can be made by keeping the cadmium piece in the electrolyte and moving the contact on the positive plate over to the negative. If the cell be *charging*, the cadmium in the liquid must be removed, and the copper end of the contact piece pressed against the negative lug, while the contact which was on the positive lug is taken away, and its cadmium end placed in the electrolyte.

(6) The charging rates are usually given by the makers, but in absence of any instructions, it may be determined approximately by calculation, taking .040 amperes per square inch of positive plate surface as normal. This can be checked after a few trials, by the length of time elapsing from beginning to the end charge, as evidenced by the voltage rising to 2.5 and vigorous evolution of gases, called "boiling." The eight hour rate is usually taken as the normal in power station cells, and the four hour rate in motor car batteries.

The maximum charging rate is that at which the cell will

absorb energy without heating more than  $25^{\circ}$  F. above surrounding atmosphere, or excessive gassing. Usually this will be found to be not greater than the two hour rate, and if it be at the beginning of charge less than this rate.

(7) The normal discharge rate may be taken as equal to the normal charge rate—usually taken as the eight hour rate. The maximum discharge rate should never be greater than the one hour rate, though it is claimed by the makers of certain Planté elements that their cells will stand discharge at the thirty minute rate, provided the full capacity be not taken out.

After determining (1) to (7) inclusive, the battery should be given several cycles of charge and discharge at normal rates, to bring it up to good working condition, before going on with the tests following.

(8) The capacity at normal discharge rate should first be determined. Charge at normal rate until the cell reaches 2.5 volts, and gasses vigorously. Note acid density and temperature during charge, at intervals of about twenty to thirty minutes. The voltage observations should be at intervals of about three minutes for the first quarter of an hour, then of six minutes, until the voltage becomes steady, after which twenty or thirty minute intervals will be often enough until the point is reached where the voltage begins to rise rapidly, when the readings should be about six minutes apart. The working up of results is greatly facilitated if the observation intervals are 3, 6, 12, 15 or 30 minutes, as these are decimal fractions of an hour, being .05, .1, .2, .25 and .5 of an hour, respectively.

When fully charged, discharge, keeping the current constant throughout the time of discharge. Note acid density, temperature and voltage as before, the voltage readings being taken at short intervals at the beginning, and towards the end of discharge, and at longer intervals where the fall is slow and steady. The constant current of discharge multiplied by number of hours duration up to the point where the voltage drops to 1.8, gives the ampere hours capacity. This result, multiplied by the *average* voltage during discharge, gives the watt hours capacity.



The temperature must be kept as nearly constant as possible, and should be between 68° and 75° F.

Cadmium readings should be taken at the beginning and end of charge, (the latter before current is cut off); just after beginning discharge; at the end of discharge, before the current flow is stopped, and occasional readings should be taken during charge and discharge. Should the voltage on charge be 2.5 and the voltage between the negative plate and cadmium less than .15, the cell cannot be considered as fully charged, and the charge should be prolonged until the negative is brought up to this value as a minimum.

If on discharge the voltage between the negative and the cadmium reaches .25 before the cell voltage drops to 1.8, the discharge should be considered as ended. Should this occur on more than one discharge, either local action or deficient capacity in the negative plate is indicated.

After finding the capacity at the normal rate, discharges should be made at the 1, 2, 3, 4 and 6 hour rates, and the capacity at these rates determined. Observations of course must be taken at more frequent intervals when discharging at high rates.

(9) The best way to make a commercial test of the variation in capacity with change in temperature, is to bring the temperature of the room to the desired point, and allow the battery to stand until it attains the room temperature. On charging, it will tend to heat, but by considerably reducing the charging rate towards the end of charge, the cell will cool down to practically the initial value if the sulphate be completely reduced.

The cell should be shielded from drafts by screens or a box, so that the temperature will be maintained constant within reasonable limits.

If a more accurate test is desired, the cell should be set inside a box or tank filled with water. Inside the box, and below the surface of the water, is placed a steam pipe, by means of which the water can be brought to any temperature higher than that of the room, and, in turn, raise the temperature of the battery.

With care, the temperature can be maintained constant

throughout charge and discharge, by controlling the admission of steam to the heating pipe.

(10) Variation in voltage with temperature would be observed at the same time as variation in capacity, and under the same conditions.

(11) The internal ohmic resistance is very difficult to determine accurately, because it is so small compared with that of any commercial measuring instrument, and also be-

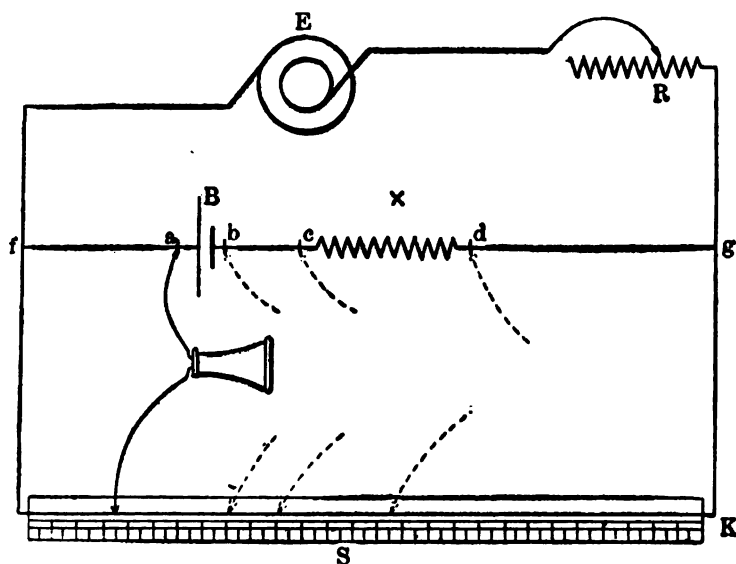


FIG. 81.

cause it is itself a variable. Many methods have been devised for measuring it, three of which are herewith given. They all, however, require careful and painstaking work to produce accurate results. The observations should be repeated many times and under various conditions.

*Sheldon's Method*, devised by Dr. Samuel Sheldon, is one of the simplest, the only apparatus required being a telephone receiver, a slide wire bridge, and an auxiliary, non-inductive resistance, of known value.

The test cell is connected up as shown in Fig. 81. E is a source of alternating current, B the battery under test, X

the known resistance, and  $S$  the slide wire bridge.  $R$  is a resistance to adjust the strength of the current. An alternating current of constant value—about twice the normal charging current—is sent through the battery and resistance  $X$ . The voltage between the extreme ends of the slide bridge is equal to the drop from  $f$  to  $g$ .

The first reading is made with the terminal,  $t$ , of the telephone receiver at " $a$ " (that is, at the point where the connection is made between the conductors and the battery lug) the other terminal " $p$ " being moved along the bridge until a point is found at which the receiver gives the least sound. This point on the bridge is then at the same potential as point " $a$ ." Similarly, readings on the bridge are found for points " $b$ ," " $c$ " and " $d$ ."

The drop from " $a$ " to " $b$ " is that due to the ohmic resistance of the cell, and is proportional to the reading on the bridge at " $b$ ," minus reading at " $a$ ." Likewise the drop through  $X$  is proportional to the reading at " $d$ " minus reading at " $c$ ." From this it is evident that

$$x : r :: (d - c) : (b - a) \dots \dots \dots (10)$$

whence

$$r = \frac{X(b - a)}{d - c} \dots \dots \dots (11)$$

$r$  being the internal resistance of the cell.

It is neither necessary to measure the current passing, nor to know the absolute values of  $a$ ,  $b$ ,  $c$  and  $d$  in volts. If these readings be simply *lengths* intercepted between the pointer  $p$  and the end  $h$ , the ratio still holds.

If the lengths are measured from the end  $K$ , then the formula becomes

$$r = \frac{X(a - b)}{c - d} \dots \dots \dots (12)$$

It is desirable that  $X$  should be small, in order that the drop across the bridge be also small, and consequently the drop across  $a$ ,  $b$  will show an appreciable length on the bridge. It

is also essential that the bridge wire be homogeneous, and of equal resistance per unit of length over its entire length.

### *Condenser Method.*

The connections and apparatus for testing by this method are as shown in Fig. 82.

C is a condenser, BG a ballistic galvanometer, *a* and *b* keys, B the test cell, and R a known resistance which should be low enough to permit full normal current to flow when connected across the battery. On depressing key *a*, the condenser receives a charge proportional to the cell E.M.F. and a corresponding throw of the galvanometer needle is pro-

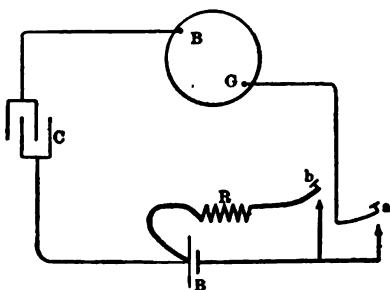


FIG. 82.

duced. Still holding *a* down, depress *b* and the potential at the battery terminals is decreased because of the drop due to the current flowing through it and R. A partial discharge of the condenser will take place, causing a reverse throw of the galvanometer needle.

Calling the throw first obtained *T*, and the second *t*;  $T - t = t_1$  is the throw which would have occurred if *b* were first depressed, and then *a*, the condenser, being without charge. After securing the first two readings, discharge the condenser by short circuiting its terminals, re-connect it as before, depress *b* and then *a*, and compare the direct reading obtained with the computed value of  $T - t$ . If they do not check, the observations should all be repeated until they are sensibly equal.

The resistance of the battery  $= r = \frac{R(T-t_1)}{t_1}$  deduced as follows:

$T$  is proportional to the E.M.F.  $= E$  of the cell.

$t_1$  is proportional to  $E - Ir$ , where  $I$  is the current flowing when  $b$  is depressed.

$$\text{then } T : t_1 :: E : (E - Ir) \dots\dots\dots (13)$$

$$I = \frac{E}{R+r} \text{ whence } E - Ir = E - \frac{Er}{R+r}$$

$$T \left( E - \frac{Er}{R+r} \right) = t_1 E$$

$$t_1 = T - \frac{Tr}{R+r}$$

$$Rt_1 + rt_1 = RT + rT - rT$$

$$rt_1 = R(T - t_1)$$

$$r = \frac{R(T - t_1)}{t_1} \dots\dots\dots (14)$$

#### *Rimingtons Method.*

The connections for testing by this method are as shown in Fig. 83.

$R_1$ ,  $R_2$  and  $R_3$  are resistances and  $B$  the test cell in the four arms of a Wheatstone bridge. In the same arm with  $R_1$  an auxiliary cell is inserted, giving an E.M.F. to oppose that of cell  $B$ .  $G$  is a galvanometer—which is preferably a sensitive d' Arsonval instrument— $S$  is a switch or key.  $R_1$  should be of about 10 ohms resistance and  $R_3$  about 0.1 ohm.

On making the connections, a small deflection will be observed due to a slight difference in the E.M.F. of the two opposing cells. On closing  $S$  a different deflection is observed.  $R_2$  must be adjusted until the deflection is the same whether  $S$  be open or closed. Then the internal resistance of

$$B = r = \frac{R_1 R_3}{R_2} \dots\dots\dots (15)$$

neglecting the internal resistance of  $E$ , which is inappreciable as compared with  $R$ .

The effects of polarization cause certain changes in the deflection, which require some rather nice manipulating to eliminate.

If polarization sets up in the test cell when switch  $S$  is closed, a current will pass from  $c$  to  $d$  because of the decrease in the E.M.F. of the cell, and the galvanometer will be correspondingly deflected. A decrease of  $R_2$  tends to cause current to flow from  $d$  to  $c$ , and produce a deflection in a corresponding direction. Therefore  $R_2$  must be gradually diminished until an impulse is observed in the latter direction.

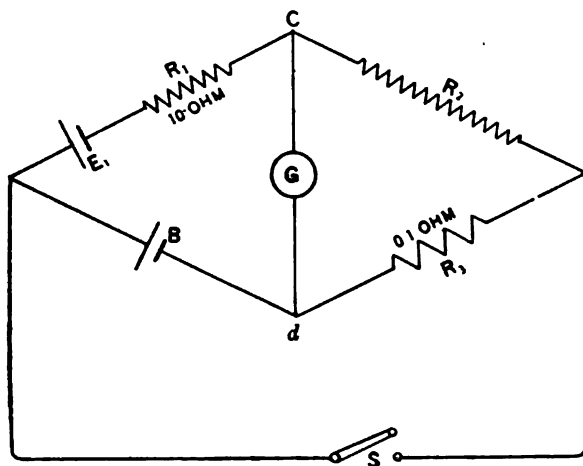


FIG. 83.

This impulse will be immediately followed by a movement in the opposite direction, caused by polarization of the test cell.  $R_2$  should be gradually increased until a point is reached at which this impulse disappears, and this value is the correct one for  $R_2$ .

(12) *Internal Virtual Resistance.*

To determine this, the cell is connected up as shown in Fig. 79.

Note voltage on open circuit; call this  $V_1$ . Then throw switch to upper position, allowing a definite current to flow into the cell, and note increase in voltage, calling this  $V_2$ .

Then open the switch and observe again the open circuit

voltage. The voltmeter pointer will not drop back immediately to its final value, but will come down slowly. Wait until the needle movement ceases before taking the reading. This sometimes is as long as 75 seconds. The last reading should be the same as  $V_1$ . Again close switch, sending same current through as before, and note voltage; call this  $V_3$ . Then by means of the adjustable resistance,  $R$ , send an increased current through the cell, and again observe the voltage; call this  $V_4$ .

From the first measurement:

$$R = \frac{V_2 - V_1}{I_1} \dots \dots \dots (16)$$

$I_1$  being the current flow in amperes.

From the second observation:

$$R = \frac{V_4 - V_3}{I_2 - I_1} \dots \dots \dots (17)$$

in which  $I_2$  is the increased value of the current.

Also test by taking the voltage on open circuit and throwing the switch to the lower position, so that the cell discharges. The virtual resistance in this case will be

$$R = \frac{V_1 - V_5}{I_3} \dots \dots \dots (18)$$

in which  $V_1$  = Voltage on open circuit;  $V_5$  = Voltage when discharging, and  $I_3$  the current flowing.

On repeating the experiment by increasing the current outflow in a manner similar to the test with inflowing current, the resistance becomes

$$R = \frac{V_5 - V_6}{I_4 - I_3} \dots \dots \dots (19)$$

in which  $V_5$  is the voltage before increase of current flow;  $V_6$  that after increase;  $I_3$  the current flowing before increase, and  $I_4$  that after increase.

Further test consists in adjusting resistances  $R$  and  $R_1$ , so that the current flow will be the same on charge as discharge; call this current  $I_0$ . Throw the switch to its upper position, and as the charging current passes in, note the voltage. Call this  $V_0$ . Then quickly throw the switch to its lower position so that the current flows out from the cells, and take the voltage reading; call this  $V$ .

$$\text{Then } R = \frac{V_0 - V}{2 I_0} \dots \dots \dots (20)$$

This last test should be tried for various values of current, and at various points of battery charge. The final determination of  $R$  is an average of the various values determined by the different tests mentioned. These values should not be greatly different for the same point of battery charge, but will vary somewhat for different points.

(13) Specific gravity variation of electrolyte is observed preferably by the insertion of a flat hydrometer in the liquid in the cell. If, however, a flat instrument is not obtainable, a small quantity of electrolyte may be drawn from the jar by means of a rubber bulb or syringe, and put into a large test tube, into which the hydrometer may be placed.

The electrolyte withdrawn is then poured back into the cell. Always stir the liquid before putting in the hydrometer or removing from the cell, in order that the specific gravity observed will be that of the entire mass of liquid.

(14) In order to determine the loss of charge on standing idle, the cell should be charged up to 2.5 volts, and then discharged down to 1.8, noting capacity, temperature, voltage and acid density. Then charge again to 2.5, and set aside for 48 hours. Bring to same temperature as that of the previous test, and discharge down to 1.8. Repeat this test, setting aside for 60 hours and again for 120 hours. The loss is, of course, equal to the capacity immediately after charge, minus that of the discharges taken after the periods of rest.

The cell should be carefully insulated so that the loss of charge may be an indication of the amount of local action.



Cadmium readings on discharge will show which of the plates has suffered the greatest loss, and consequently the most local action.

In working up the data obtained, the quantities (15) to (19) are easily deduced. In making comparative tests of capacity per pound weight of several batteries, there should be the same number of plates in each cell. If one cell should contain more plates than the others, it would have a marked advantage in such a test, for the reason that the end negative plates weigh nearly, if not quite, as much as the other negatives, although they give only about half the capacity of the other negatives, and they therefore tend to increase the weight of the cell, without a corresponding capacity increase. The fewer the number of plates the greater will be the proportionate increase of weight, from this cause. Therefore, no comparative test is fair to all batteries, unless each contains the same number of plates.

No capacity test is of value unless the temperature at which discharge takes place is specified, and in comparative tests all discharges should be made at the same temperature.

(20) The capacity temperature coefficient is a factor which, if the capacity at one temperature be multiplied by it, the product resulting will be equal to the *increase* in capacity for each degree increase in temperature, or, expressed algebraically,

$$Ct_2 = Ct_1 + jCt_1 \dots \dots \dots (21)$$

where  $Ct_1$  = capacity at any given temperature,  $j$ , the temperature coefficient, and  $Ct_2$ , the capacity at a temperature one degree greater.

If the capacity at several temperatures be found, then the temperature coefficient =  $j$  can be computed as follows:

By definition,

$$Ct_2 = Ct_1 + Ct_1 (t_2 - t_1) \times j \dots \dots \dots (22)$$

in which  $Ct_1$  = capacity at given temperature  $t_1$ ;  $Ct_2$  = unknown capacity at some higher temperature,  $t_2$ ; and  $j$  the temperature coefficient.

Solving:

$$j = \frac{Ct_2 - Ct_1}{Ct_1 \times (t_2 - t_1)} \dots \dots \dots (23)$$

It will be found that  $j$  will vary somewhat for different stages of temperature increase; and it will be greater from a low temperature to one only moderately higher, than from a high temperature to one still higher. In other words, the increase of capacity per degree increase in temperature is not a linear function, but varies; decreasing as the temperature rises. Between 50° and 80° F., however, the limiting temperature usually found in practice,  $j$  is practically constant.

There will also be a different coefficient for each *rate* of discharge, the greater values being for high rates.

(21) Curves of charge and discharge are plotted in the usual manner, from the voltage observations made during the various tests. From these, the general performance of the battery may be seen, together with the various changes which take place during the periods of charge and discharge.

(22) Efficiencies at normal rates, are determined from observations on charge and discharge, and the ratio of the amount of energy supplied to that delivered. Efficiencies at rapid discharge rates, however, must be the subject of special tests, consisting of several cycles of charge and rapid discharge.

Start with the cell fully charged, and end with it in the same condition, the number of charges and discharges being equal. The efficiency will be equal to the sum of the amounts of energy delivered by the several discharges, divided by the sum of the amounts of energy put in on the several charges.

(23) The relation of electrolyte density to the ampere hours discharged, is easily computed from the discharge data and corresponding hydrometer readings. Usually the curve of variation in acid density is plotted on the same sheet with the voltage curves, and, if these latter be for a constant current of charge or discharge, the density for any ampere hour output can be read off directly. Fig. 84 is an example

of a specific gravity curve combined with the voltage curves. The discharge rate is 16 amperes. At the beginning of discharge the density is 1.280; at the end of the first hour, or 16 ampere hours, the density is 1.253; at the end of the second hour, or 32 ampere hours, 1.226, and so on, the final value at the end of discharge being 1.148.

A knowledge of this variation in density is useful, as giving an indication of the state of charge left in the cells when they

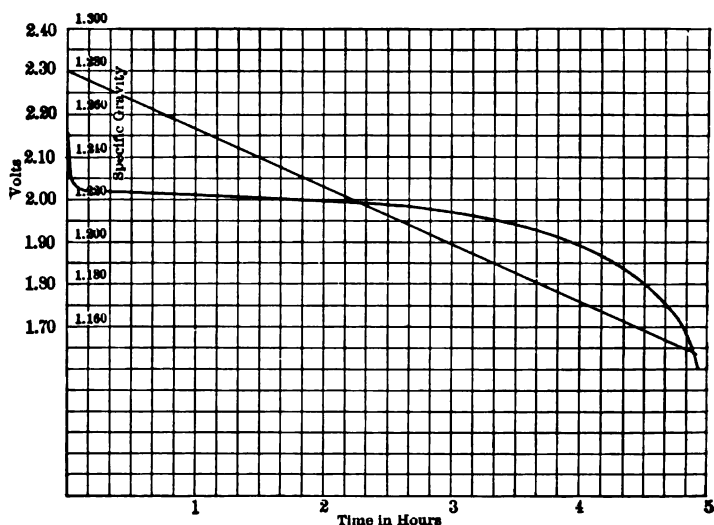


FIG. 84.

have been partly discharged, provided the cells are in good condition. If the density is found to be appreciably less than it should be, as shown by tests when in good condition, the cell is undergoing discharge, either from leakage or internal discharge, and the resulting formation of sulphate decreases the density. Therefore, if the density range and variation be known, it becomes a useful check on the condition of the cell. Increased density merely shows evaporation.

(24) With a previous knowledge of the requirements necessary in a battery for it to successfully meet given conditions, and all the foregoing data in hand, a careful con-

sideration of all the questions involved will show whether or not the battery is adapted for the service it is intended to give.

(25) No test other than that of continual use, extending over a long period—possibly years—can definitely determine the durability of a battery. It is, however, possible to form a reasonably correct idea by subjecting a cell to 150 cycles of charge and discharge, of 6 hours each, the half cycles (charge or discharge) being at the 3 hour rate. This requires 900 hours, or about 38 days of continuous operation, and a change of connections from charge to discharge, or vice

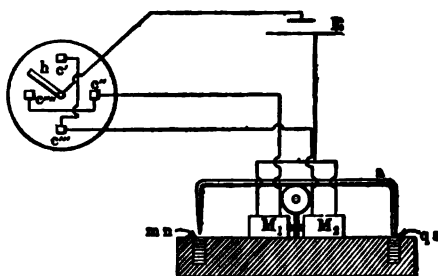


FIG. 85.

versa, every 3 hours. To perform this work by hand, and continuous personal observation, would require two or three shifts of men, and be both tedious and costly. A simple automatic apparatus, however, does the work, and only requires a daily inspection of a few minutes.

This apparatus consists of an electrically operated time switch, double pole and double throw, and is made of a cheap clock, two electro-magnets and an oscillating shaft carrying contacts which dip into mercury. Fig. 85 shows the general arrangement and connections of the automatic time switch. The face and hands of the clock are removed, and a sheet of fibre is substituted for the face. Screwed thereto are four contacts, *c, c, c, c*, insulated from all other parts, and equally spaced  $90^\circ$  apart around the circle. They are slotted where the holding screws pass through, to allow accurate adjustment. In place of the hour hand, is sub-

stituted a light, strong copper contact piece, at its end, which can make light yet firm and definite contact with c, c, c, c. A brush of fine wires will not do, as it lacks definiteness of point of contact.

$M_1$  and  $M_2$  are small electro-magnets, of about 2 ohms resistance, operated by a cell E. m n and q s are mercury cups forming the terminals of a double pole, double throw switch, a plan view being shown in Fig. 86, which diagram also shows the method of connecting up the test cell. G is a source of current;  $R_1$  and  $R_2$  adjustable resistances; B the battery to be tested, and S the two-way switch.

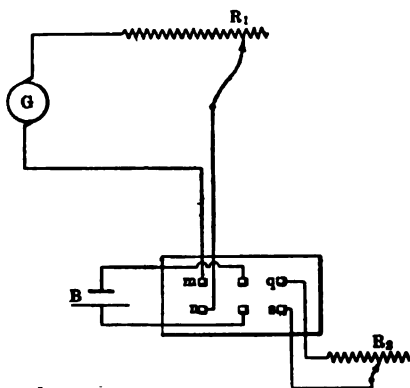


FIG. 86.

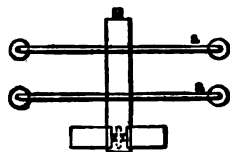


FIG. 87.

A good way to make the mercury switch cups is to bore holes about one inch deep into a piece of  $1\frac{1}{2}$  inch board, as indicated in Fig. 85.

The oscillating switch is made of two pieces of heavy wire, a, a (Fig. 87), fastened at their middle points to the small short shaft d, as shown, and insulated therefrom. This shaft is supported on proper bearings, and on its lower side has fastened an iron armature oscillating between the two magnets,  $M_1$  and  $M_2$ . It is obvious that if  $M_1$  be excited, the armature will be attracted towards the left, the shaft will rotate slightly and contact will be made at q and s, while it is opened at m and n. If  $M_2$  be excited, the reverse operation will take place.

Referring now to Fig. 85, it will be seen that the operating cell E, which is used to excite the magnets  $M_1$  and  $M_2$ , and may be any type of battery primary or secondary, is so connected through the clock contacts and hand that when the hand touches c and c',  $M_1$  is energized, and when it touches c' and c'',  $M_2$  is energized.

Adjust the contacts by timing with a watch, so that the interval from the making of one contact to the making of the next, is exactly three hours. Then connect up as shown.

Adjust  $R_1$  and  $R_2$  so that the current flow through them on closing the charge or discharge circuit, is the 3 hour rate, and the test is ready to begin.

As a precaution, a revolution counter may be connected to the oscillating shaft d, to show the number of cycles through which the cell has been operated.

If, at the end of 150 discharges, the cell is still in fair condition, it may be considered as durable. The appearance of the plates will indicate whether or not they bear promise of much subsequent work.

## APPENDIX TO PART I.

### TABLE OF ENERGY EQUIVALENTS.

Assuming 1.94 as the *average* voltage per cell throughout discharge

385 ampere hours = 1 h.p. hour *per cell*.

516 " " = 1 k.w. " " "

1 ampere hour =  $\begin{cases} .026 \text{ h.p. hour.} \\ .0205 \text{ k.w. hour.} \end{cases}$

1 Watt = .001335 h.p. hour.

2655 foot pounds.

367 kilogram-meters.

3600 joules.

### LEAD.

Conductivity = 7 per cent. that of copper (approx.).

Resistance = 14 times that of copper.

Allowable current density, 70 to 90 amperes per sq. in.

### TABLE OF VOLTAGES.

						Voltage in 1.200 sp. gr. sulphuric acid.
Lead	electro positive to Lead peroxide.					1.46
Lead sponge	" " " " "					2.00
" "	" " " Lead					—
" "	" " " Antimony.					.52
Antimonious lead	" " " Lead peroxide.					1.4
Lead	" " " Antimony.					.22

### DEPOSITION OF LEAD.

Weight of lead deposited by an electric current, per sq.

in. of surface of cathode =  $\frac{I \times T}{S \times 7.4}$  ounces avoirdupois, where

I = current in amperes.

T = time in hours.

S = surface of the cathode in sq. ins.

Weight deposited per sq. cm. =  $3.847 \times \frac{I \times T}{S}$  grams, in  
which S = area of cathode in sq. cms.

The total weight of lead deposited =  $\frac{I \times T}{7.4}$  or .1352 oz.  
av. per ampere hour.

## MISCELLANEOUS.

Wt. per cu. inch of any substance.

=  $.577 \times G$ . oz., in which G is specific gravity or density.

This formula is useful in computing weight of a given  
volume of electrolyte.

Increase in volume of Pb when converted to  $PbO_2$  = 40%

“ “ area “ “ “ “ “ “ = 25.3%

“ “ length “ “ “ “ “ “ = 11.9%

TABLE OF SPECIFIC GRAVITIES AND WEIGHTS.

	Sp. Gr.	Wt. Oz. Per Cu. In.
Lead, metallic.....	11.4	6.56
“ sponge.....	8.2	4.73
“ peroxide.....	6.8 to 9.4	3.9 to 5.4
Litharge } .....	9.4	5.4
Minium }		
Antimony.....	6.7	3.8





## **PART II**

### **AUXILIARY APPARATUS, SYSTEMS, APPLICATIONS**



## CHAPTER XXIII.

### USES OF BATTERIES.

---

Storage batteries find their principal uses in connection with power station and distribution work in (1) storage of electrical energy; (2) regulation of station output; (3) regulation of station voltage; (4) compensation for feeder drop; (5) insurance against shut downs; (6) as an equalizer on three-wire systems, and (7) a combination of any or all of the above.

#### (1) Storage.

As is well known, the load on any electric power station, whatever its character, differs from that on the power plant of a textile mill or other manufactory, in that it varies during the 24 hours from a minimum to a maximum. It also differs from a mill power plant in that the fuel consumption and the cost of producing a horse power hour is much less in the latter case than in the former, due to the fluctuating demand on the electrical plant. In laying out the plant equipment the question of handling the maximum load—which usually lasts only a short time—arises. Whether it is best to put in sufficient generating machinery and boilers, to carry it and shut some of them down twenty out of the twenty-four hours, or whether to install a battery to carry the peak, and if the latter, what proportion of the peak the battery shall take care of.

The battery will be charged when the load is light, and discharged when the demand is heavy, and thus partly equalize the load on the generating equipment with a resulting higher efficiency, in addition to giving the necessary output to supply the maximum demand on the system.

On the other hand, there are losses in the efficiency of the battery equipment which may offset all these advantages. Whether a battery will pay dividends or not, and if so, the

ratio of battery capacity to capacity of generating equipment, depends on

- a. Character of generating equipment.
- b. Cost of fuel.
- c. Cost of labor.
- d. Character of service.
- e. Load variations.
- f. Cost of battery.

The cost of labor enters into the question only when the battery plant is to be so large that all or a large part of the boilers and generators may be shut down, at periods of light load, long enough to dispense with some or all of the attendants. This condition often exists in isolated plants having a very small night load.

The character of the generating equipment determines the fuel consumption, for a given daily output which varies between wide limits, and its increase over the fuel consumed for an equivalent number of horse power hours at steady load.

The cost of fuel per ton shows the value of the amount saved by steadying the load.

Character of service enters into the question apart from considerations of economy. With certain classes of service, a battery becomes a necessity, regardless of the financial considerations. A generator supplying current to both lights and elevators is a case in point. Without a battery, the winking of the lights when an elevator is started becomes intolerable. A battery will take up the load fluctuations, and prevent this trouble. This, however, is an application belonging under the head of voltage regulation instead of power storage.

Load variations give the data from which the coal consumption is computed, as are also the battery and booster capacities. Cost of battery equipment—which means the excess cost of a plant with a battery over an equivalent plant without one—shows the additional investment required, and the consequent increase in the interest and depreciation account. This quantity is often negative, *i. e.*, the cost of equipment with battery may be less than that

of a plant to carry the same load, with generating capacity sufficient for the maximum demand.

(2) *Regulation of Load.*

Used on regulation, the function of the battery is to steady fluctuating loads. The generator delivers a steady current, while the external load rapidly fluctuates above and below this generator output. The differences are absorbed or given out by the battery, that is, the battery received a charge when the load is less than the normal generator output, and it discharges when the load is greater than the normal generator output, the rate of charge and discharge at any instant being equal to the difference between the generator current and that of the external circuit.

The economy of steam engines is worst on a rapidly fluctuating load, and the quick changes cause shocks and strains in the machinery which greatly increase the depreciation and repairs. A battery equipment on such a load produces a marked improvement in the fuel economy, the general operation and reduces the maintenance, besides, in many instances, allowing one or more machines to be shut down. As has been seen, the efficiency of a battery which alternates rapidly in its charge and discharge is very high, and these are the conditions in this case, besides which the amount of energy stored in the batteries is very small compared with the total station output. The battery losses being proportionately small, the electrical efficiency is not appreciably lowered while the plant efficiency is greatly increased. Obviously, the battery may be used both to equalize the momentary fluctuations and carry the peak, when the steady demand increases.

(3) *Voltage Regulation.*

The voltage regulation is obtained by regulating the station output. Certain classes of service demand voltage regulation though output regulation *per se* would not be required.

(4) *Compensation for feeder drop.*

When batteries are installed at the end of a long feeder, which supplies current to a rapidly and widely fluctuating load on which the voltage drop must not exceed a certain

amount, a saving of copper is effected, and in many cases this saving exceeds the cost of the battery.

Without the battery the feeders must be large enough to carry the *maximum* current at the prescribed voltage drop, while with the battery the feeders need only be large enough to carry the *average* current. The ratio of the average to the maximum demand determines the value of the application in this case. Here, too, the battery has an effect to equalize the instantaneous fluctuating load on the station, and generating equipment, and it may also carry its individual peak.

(5) Safeguard against shut down.

There are a few cases in which a battery serves as a safeguard against breakdowns merely. For instance, when connected across exciter bus bars in a large power station equipped with alternating current generators. If an exciter should fail, the plant would have to shut down. A small battery kept charged would do no work and pay no dividends, but it would effectually prevent any such contingency, and the insurance effected would be well worth the cost.

As a rule, however, batteries are installed to equalize fluctuations, carry peaks and act as safeguards against breakdowns, all of which one battery is capable of accomplishing.

(6) Acting as an equalizer on a three-wire system, which is fed by 240 volt generators.

When installed as an equalizer, the battery is connected across the outside wires, the neutral being connected to the cell in the middle of the series. Should unbalancing of the system occur, one-half the cells receive a charge, and the other half a discharge.

(7) There are many combinations of these important functions which a battery performs, the most important of which will be clearly brought out later, by concrete examples.

## CHAPTER XXIV.

### END CELLS.

The external voltage of a storage battery being variable, changing with the amount of charge it contains, and with the direction of current flow, devices are required to compensate for this variation and maintain a constant potential on the line which is supplied by the battery.

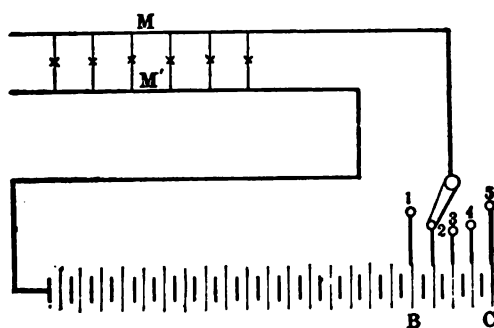


FIG. 88.

The methods which are in use are the following:

- (1) Variable resistances.
- (2) End cells.
- (3) Counter E.M.F. cells.
- (4) Boosters.
- (5) Combinations of the above.

Referring to Fig. 88, MM' are supply mains, AC the battery, 1, 2, 3, 4 and 5 contacts, each of which is connected with an end cell; L a movable contact arm connected to the main M. When the battery is fully charged, the voltage per cell on beginning of discharge will be about 2.08 and if



MM' be a 110 volt circuit, the number of cells required in series would be  $\frac{110}{2.08} = 53$ .

When the battery is near exhaustion, however, the voltage per cell on discharge is 1.8 and the number of cells required

in series =  $\frac{110}{1.8} = 61$ . Therefore it is necessary to gradually

vary the number of cells in circuit from 53 to 61, between the beginning and end of discharge. The installation would consist of 61 cells, eight of which would be end cells, with taps running to contacts on the end cell switch. These switches are considered in detail in chapters XXVII and XXVIII.

The taps must be of sufficient cross sectional area to carry the maximum current discharged as each becomes one side of the system when the end cell contact arm is moved from one button to the next.

As the end cells are gradually cut out as discharge proceeds, it is evident that they need not be of the same capacity as the cells forming the main body of the battery. Theoretically, they should taper off in size, the extreme outer cell being the smallest, and the cell adjacent to the main battery of the same capacity as the main cells. In practice, however, it is customary to install all the cells of uniform size, and in case of loss of capacity or accident to any of the main cells, one of the end cells may be substituted for it, the defective cell taking the place of the removed end cell, and furnishing sufficient capacity to make the system operative.

In charging, the extreme end cell—the one last cut in on discharge—will soon be fully charged, as there was but little current taken out of it. The end cell switch must then be moved on to the next point, cutting out this charged cell. When the next cell is fully charged, it is also cut out by moving in the end cell switch and so on until all the end cells have been cut out. All the cells in the main battery will, of course, be charged at the same time. Care must be taken

to cut the end cells out, as they become fully charged, or they will be overcharged, and possibly to such an extent as will injure them.

Fig. 89 shows a type of installation in which the end cells must be larger than those in the main battery. G is the supply generator in which the voltage may be varied above that of the supply circuit MM<sup>1</sup>. AB is the main battery, and Bc the end cells. S<sub>1</sub> and S<sub>2</sub> are end cell switches.

The maximum voltage of the generator must be great enough to charge all the cells in series, and as the battery

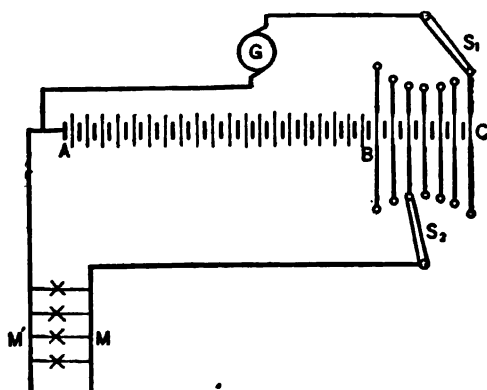


FIG. 89.

fills up the movable arm of S<sub>1</sub> is carried along towards B cutting out the end cells.

The arm of S<sub>2</sub> is placed on the contact which puts in series the exact number of cells required to give the proper voltage across the supply mains MM<sup>1</sup>.

It is evident that the current flowing through AB is the charging current, while the current through the end cells included between the arms of S<sub>1</sub> and S<sub>2</sub> is that through AB, plus the current used in the supply mains. The end cells in this system must therefore be large enough to admit of the passage of total current used in the system. The number of end cells will be the same in any case—about 13½ per cent. of the total number of cells in the battery.

## CHAPTER XXV.

### COUNTER E.M.F. CELLS.

---

Instead of end cells or resistances, counter E.M.F. cells are sometimes used to maintain the line voltage constant. These cells are made of grids or other lead plates immersed in ordinary electrolyte. The plates are not formed or covered with active material and possess no capacity. Their sole function is to set up an opposing voltage to the discharge current, and cut down the net voltage across the line by an amount depending on the number of counter cells in series which oppose the E.M.F. of the main battery. As the voltage of the main battery falls, the counter cells are cut out and the external voltage of the system kept constant.

The same maximum number of useful cells are required as would be if some were tapped off as end cells, viz.:  $\frac{E}{1.8}$  in which  $E$  = voltage of the system.

The same number of counter cells are required as would be of end cells if the latter were used, that is: about  $13\frac{1}{2}$  per cent. of the number of cells in the battery. The counter E.M.F. cells require the same connections to a multiple point switch as do end cells. It is seen, therefore, that the use of counter cells does not cut down the installation in any way, but adds on  $13\frac{1}{2}$  per cent. of cells of a different type from the useful cells, thus complicating the installation and adding to its cost by an amount equal to the value of the counter cells. For these reasons they are scarcely ever installed, and to do so, except in cases of plants which receive little or no attention when charging, is bad engineering. The one valuable feature of an installation of this kind lies in the fact that all the cells of the working battery are uniformly charged and discharged, while with end cells, these

latter are never worked to their capacity, and are subject to severe overcharge, unless some attention is given the plant during the period of charging, and the contact switch shifted as the cells are filled up.

As a matter of fact, in practice the end cells are nearly always in better condition than those in the main body of the battery, and the attention necessary to prevent injurious overcharge is very slight, so that, except in very rare instances, the counter E.M.F. cell may be considered as having no place in the storage battery practice of the present time.

## CHAPTER XXVI.

### RESISTANCES.

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Resistances are often used for voltage regulation in small installations where efficiency is not of so much importance as simplicity and low first cost.

They may be made in any form and of any resistance material. Cast iron and German silver are used generally, though carbon piles have been found cheap, easily adjusted and compact.

Data pertaining to metallic resistances are to be found in various electrical works and therefore are not given here.

A detail description of the carbon pile resistance would not be out of place here. Fig. 90 shows one form of this device, made up of carbon plates one-quarter of an inch thick by four inches square, piled up, forming a laminated prism of carbon 22 inches high, containing 88 plates. The bottom plate is fixed against the iron base, and the conductor leading to one terminal is firmly attached to it. The top plate is connected to the other terminal, both terminals being fixed on the iron cover plate, forming the top of the frame.

The iron cover and base plates are held together by means of four iron rods, which pass through the four corners of the plates, the lower ends of the rods being provided with threads and nuts. These rods pass through long porcelain tubes, and form a retaining



FIG. 90.

cage or set of guides to hold the carbon plates in position. The porcelain tubes serve the purpose of insulators, and also act as spacing or compression pieces against the ends of which the cover and base plates are tightly pulled by the nuts on the rods.

These tie rods are also insulated where they pass through the cover and base plates, so that there is no path for the current from the top to the bottom of the pile, except through the carbon plates.

A thumb screw passes through the middle of the cover plate, having on its end a flat iron plate which presses on the top carbon plate. By means of this screw the pressure compressing the pile together, is regulated and the resistance varied as desired.

The pile shown and of dimensions given, can carry 25 amperes at minimum resistance—2 ohms—and dissipate 1250 watts.

If the current be too great, occasional flashes will take place from plate to plate.

## CHAPTER XXVII.

### END CELL SWITCHES.

When end cells are used for regulation, a special form of switch, termed end cell switch, must be installed. The purpose of this device is to cut cells in or out, as may be necessary to maintain a constant voltage across the line. These switches commonly consist of a number of contacts equal

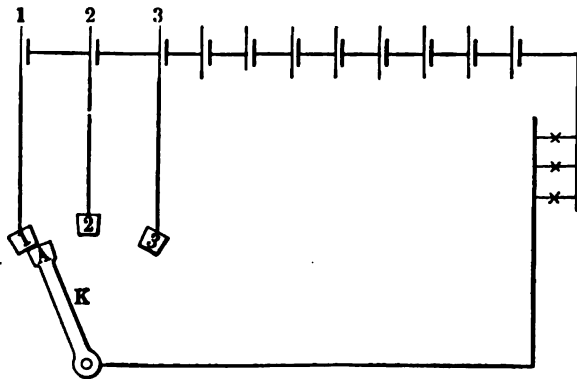


FIG. 91.

to one more than the number of end cells, and a moving contact arm. Each end cell is connected to a contact piece, the connections being made in regular order, so that adjacent contact pieces are connected to end cells that are also adjacent. Fig. 91 shows diagrammatically how the connections are made, and it is obvious that, as the moving contact arm travels to the left, more cells are gradually put into the series circuit.

The end cell switch is more complicated than an ordinary contact switch, because it is necessary to avoid opening the circuit in moving from one point to the next, and likewise

to avoid short circuiting any of the cells. Referring to Fig. 91, it is seen that if the end A of the moving arm K leaves the contact 1 before it touches contact 2, the lighting circuit will be opened. If it touches 2 before it leaves 1, the cell No. 1 will be short circuited.

There are three methods by which this short circuiting is avoided when the two adjacent contacts are connected by the moving contact arm. They are as follows:

- (1) Double contact on arm joined by resistance.
- (2) Double contact on each end cell connection joined by resistance.
- (3) Counter E.M.F. cell which is interposed in the circuit.

The first of these is the most universally used, and quite

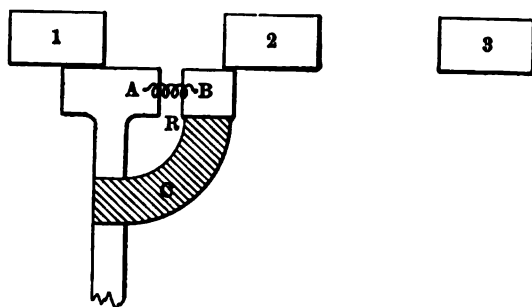


FIG. 92.

adequately meets all requirements. Fig. 92 shows the principle of its operation. 1, 2 and 3 are contacts joined to corresponding end cells. A is the main contact on the moving arm. B is an auxiliary contact fastened to A by the insulating piece C, and R is a resistance connecting A and B. The arm is shown in the act of passing from contact 1 to contact 2. A has not left 1; B is on 2 and therefore the circuit is not broken. The current from 2 to the outside circuit passes through R, which is of such low resistance that it causes no perceptible drop in the outside circuit, yet it is great enough to prevent the cell from being short circuited, and discharging an excessive amount of current, for, although



the resistance is low, the short circuiting voltage is also low, being simply the 2 volts of the single cell.

The arrangement of a double contact on each connection with a resistance between the two contacts, as shown in one of its forms in Fig. 93. *a, a, a, a,* are the main leads to their respective contacts; *b, b, b, b,* are auxiliary connectors to the auxiliary contacts. These connectors are made of some resistance metal—generally iron—that opposes the flow of current sufficiently to prevent a short circuit. It is immaterial, of course, where the resistance is placed, or how connected, if it is interposed in the circuit at the time two adjacent contacts are connected together.

The smaller sizes of end cell switches are made circular,

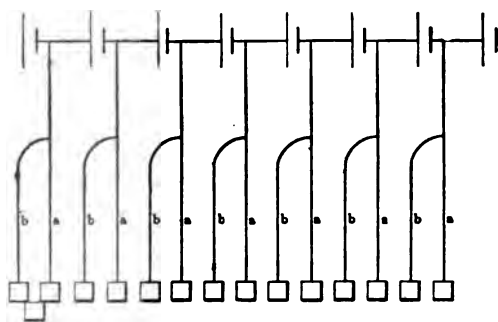


FIG. 93.

that is, the contacts are laid out around a central pivot or axle about which latter the moving contact arm turns. Plate III shows an elevation and cross section of a switch of this kind for handling 11 end cells, and with a carrying capacity of 300 amperes normal.

The edges of the contact pieces are radial, and the distance of separation is one and one-eighth inches. The terminals of the contacts are shown on the back of the panel.

The gaps between the contact strips are filled flush with flat thin pieces of fibre, making the surface from contact to contact smooth and even.

The moving contact arm *A*, carries on its under side a double ended, laminated contact piece *C*, the outer end of





which rests on the smooth circular track of fibre and contacts travelling on it as the hand wheel E is turned. This end, therefore, can be placed over any contact piece.

The inner end of the moving contact piece rests on a solid circular plate of copper F, which is provided with the terminal D.

Since the moving contact connects the ring F with any of the contacts spaced around the circle, any end cell may be connected with the terminal D, as required.

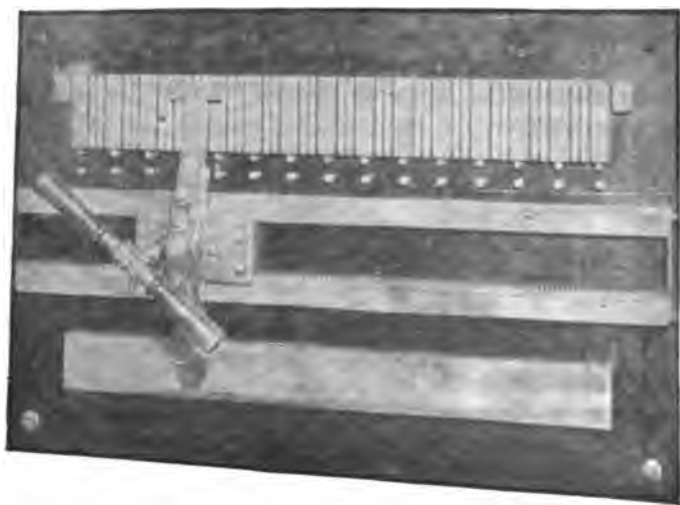


FIG. 94.

The auxiliary contact, by means of which the breaking of the circuit in passing from one contact to another is avoided, is shown at H, and consists of a five-eighths inch round carbon passing through a hole in arm A. This hole is drilled in an offset on the arm, as shown, and therefore is in advance of, or behind the main contact piece C, according as the motion is clockwise or the reverse. The hole is bushed with fibre (see section), and the carbon contact is therefore insulated from the arm and the moving contact. A coil of resistance of German silver connects the carbon to the arm, and consequently to the main moving contact.

It may be noted here that the proper current densities for contacts are 60 to 70 amperes per square inch with ordinary contacts, and 225 to 250 amperes per square inch in laminated leaf contacts. The latter are used almost exclusively on switches of 300 amperes capacity, and above.

End cell switches in the larger sizes are made straight, the movable contact moving along a screw. Fig. 94 shows one of this kind, made by the Electric Storage Battery Company.

The type of end cell switch in which a counter E.M.F. cell is used, instead of a resistance, is shown diagrammatically in Fig. 95.

As is seen, there are two sets of contacts, two contact bars, A and B, and two moving contact arms, L and M. The end cell connections are joined directly to  $C_1, C_2, C_3$  and  $C'_1, C'_2, C'_3$ . The contacts are so spaced that  $C_2, C_3, C_4$  are below or opposite to spaces between  $C'_1, C'_2, C'_3$ . The moving arms L and M travel along together, but are insulated from each other, as are the bars A and B. T is the terminal of the end cell side of the system. The operation of the switch is as follows:

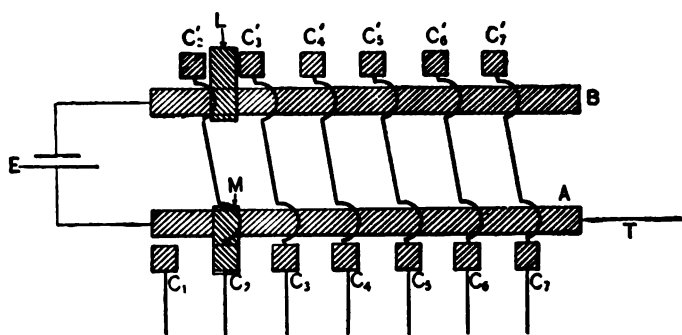


FIG. 95.

A and B, and two moving contact arms, L and M. The end cell connections are joined directly to  $C_1, C_2, C_3$  and  $C'_1, C'_2, C'_3$ . The contacts are so spaced that  $C_2, C_3, C_4$  are below or opposite to spaces between  $C'_1, C'_2, C'_3$ . The moving arms L and M travel along together, but are insulated from each other, as are the bars A and B. T is the terminal of the end cell side of the system. The operation of the switch is as follows:

In the position shown,  $C_2$  is connected through M to A and thence to T; L, being on a space, is open circuited. As L and M travel toward the right, L moves on to  $C'_1$  and joins it to B before M moves off to  $C_2$ , and the circuit to T is made through E, which sets up a counter E.M.F. of over two volts,

and although the two adjacent cells are joined to T at this instant, short circuit is prevented by the counter E.M.F. of E.

Further movement brings L fully over  $C_3$  and M over a space, the current all passing through E, and though one end cell has been added to the circuit, no rise in voltage has occurred because the counter E.M.F. of E neutralizes the voltage of the added cell. As L and M continue their motion M reaches  $C_3$  and at that moment the voltage of the system

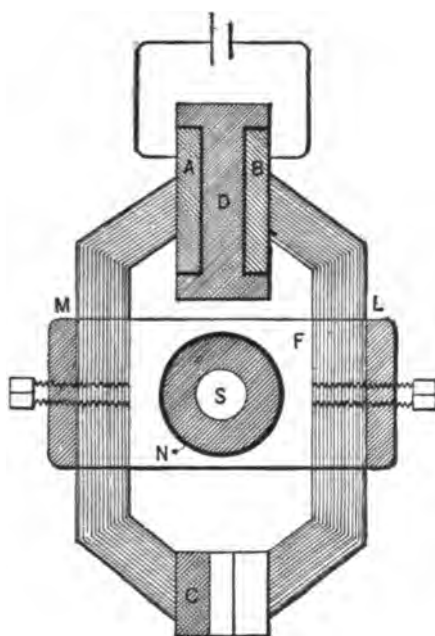


FIG. 96.

is raised. When M is in its final position over  $C_3$ , L is on a space.

It is obvious that a resistance between A and B in place of the cell E, would serve to prevent a short circuit across the end cells.

This switch can be modified in many ways, the principle being retained; for instance,  $C_1, C_2, C_3$  may be directly below or opposite to  $C^1_1, C^1_2, C^1_3$ , and one contact arm set in advance of the other an amount equal to one-half the pitch of the end cell contacts.

In practice, it is usual to construct these switches as indicated in Fig. 96. The contact bars A and B are mounted on opposite sides of a longitudinal bar D, and insulated from each other. Directly beneath or opposite, are the contacts  $C_1^1, C_1^2, C_1^3$ , and  $C_1, C_2, C_3$ . L and M are made of bent laminated strips set in a cast iron framework F F, and insulated therefrom. A sleeve nut N, is integral with the frame F F, and through it passes a screw S, by means of which the contact arms L and M are caused to travel along the rows of contacts. The contacts are cast in pairs and arranged as shown in Fig. 97, which is a plan view.

A form of end cell switch devised by Verity & Co., of England, and shown herewith, in Fig. 98, admits of changing

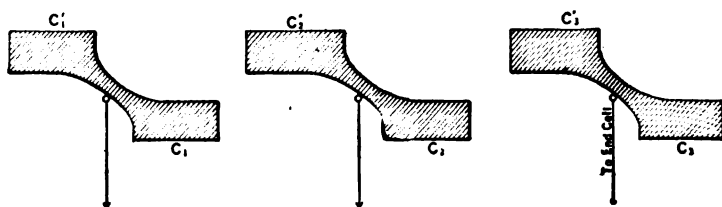


FIG. 97.

the number of cells in circuit by steps of one without the use of a contact for each cell.

The arrangement, as indicated, consists of two sets of switches,  $S_1$  and  $S_2$ .  $S_1$  consists of two independent copper contact rings and such a number of contacts as may be necessary, all arranged concentrically and insulated from each other. In the figure, 10 and 11 are the contact rings, 1, 2, 3, 4 the contacts. Two independent contact arms A and B join the rings 11 and 10 respectively on the contacts. A always precedes B by a given amount, when the rotation is clockwise. When the proper number of cells are cut in or out, and the moving arms come to operating positions, both arms are on the same contact.

Between each contact and the adjacent one, is connected a group of four cells as shown. Therefore, in passing from one

contact to the next, four cells are added or removed from the circuit.

$S_2$  consists of four contacts and a moving arm C, carrying at its outer end a double contact with a resistance between the two parts as before described. This arm turns about a point to which the terminal of the system is joined.

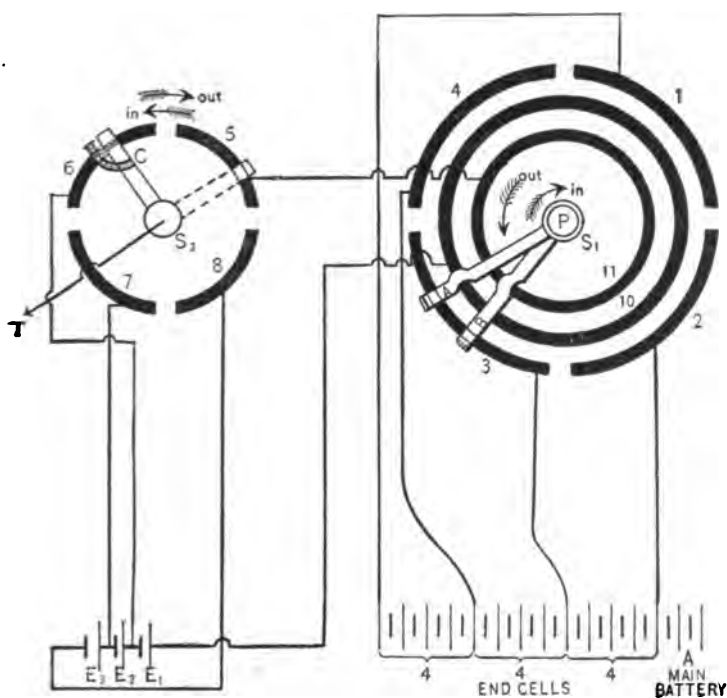


FIG. 98.

In addition to the main cells and groups of four end cells, there are three additional end cells,  $E_1$ ,  $E_2$  and  $E_3$ , as shown. The total number of cells in a given battery, however, is the same as in any other system using end cell regulation.

Ring 11 of  $S_1$  is joined to contact 5 of  $S_2$  and ring 10 is connected to contact 6 through  $E_1$ ; that is,  $E_1$  is in series with 11 and 6.  $E_2$  is in series with 6 and 7, and  $E_3$  with 7 and 8.



A, B and C are so geared together that A and B move forward one contact of  $S_1$  when C makes a complete revolution.  $S_1$  and  $S_2$  may be separate switches connected by a shaft and gearing, or the contacts on  $S_2$  may be concentric with those of  $S_1$  and the arm C, turn about the pivot P, provided there is no electrical connection between it and A and B. It is also obvious that this device may be developed into a longitudinal switch.

The operation is easily followed from the diagram. In the position shown, five of the fifteen end cells are in circuit. As C turns in the direction of the arrow marked "in" and passes on to contact 7, another cell is cut in, and at 8 another, making seven end cells in circuit, the current passing via arm B through  $E_1$ ,  $E_2$ , and  $E_3$  to 8. The switches are so geared together that when C reaches 8, A begins to move off the end of the contact on which it is travelling, and as no current is passing through it, the circuit is not broken. A and B, therefore, are simply ordinary brush contacts.

By the time C has moved to 5, A has moved to contact No. 4, and current flows to T through A, no longer passing through B, and eight end cells are now in circuit. As C continues to move in the "in" direction,  $E_1$ ,  $E_2$ , and  $E_3$  are added one by one, until A and B pass on to the next contacts of  $S_1$  and so on. In designing this switch, the number of contacts on  $S_2$  must be equal to the number of cells in each group connected between the contacts of  $S_1$ . The total number of end cells = number of contacts on  $S_1$ , multiplied by number contacts on  $S_2$ , minus one. This is a very economical switch where the batteries are connected across high voltage circuits requiring a large number of end cells, and the current carried is large, but for a small number of end cells or small currents the ordinary types are cheaper to install.

One of the principal savings—in fact; the greatest—is in the reduction of the number of conductors from the end cells to the switch. As end cell switches cannot be installed in the battery room because the copper is attacked by acid fumes, and each end cell must be connected by a conductor capable of carrying the total current output, the cost of

copper and its erection is often very great, amounting sometimes to as much as fifteen per cent. of the cost of the entire installation.

The switch just described requires only eight leads for fifteen end cells, or nine for nineteen end cells, a reduction of nearly 50 per cent. in end cell copper as compared with the ordinary system in which there is a separate lead for each end cell.

## CHAPTER XXVIII.

### AUTOMATIC END CELL SWITCHES.

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The switches before described are moved from one contact to the next by hand, and require the attention of the station attendant.

Motor driven switches have been devised which are actuated by closing a switch or contact at the switchboard and which are now in successful use. These obviate the necessity of manual operation.

In this country, they are controlled by a small double switch, which the attendant closes to one side or the other, according to the direction in which the moving contact arm is desired to travel, and actuated by a push button. In Europe, however, there are a number of installations in which the controlling switch is closed by a relay, the latter being actuated by any form of contact voltmeter—such as a spring controlled solenoid. These are of course completely automatic. They are, however, somewhat more complicated, and in case the contact maker or relay should stick or fail to move, the result might be harmful to the battery. For these reasons, they have never come into use in this country, the semi-automatic or hand switch controlled type being almost universally used.

The fact that the moving contact arm must travel a definite distance each time, makes the design of an automatic end cell switch much more complicated than would appear at first sight. If the switch be set in motion and the current actuating the driving motor be stopped too soon, or allowed to flow too long, the result will be a lapping or bridging of contacts. \* For this reason every automatic end cell switch must be so designed that though it is initially set in motion by some form of switch or contact it will move a

definite distance after starting, equal to the pitch of the cell contacts, regardless of the opening of the actuating switch.

The simplest of the automatic switches is shown in Figs. 99, 100 and 101. Fig. 99 is a front view, Fig. 100 a vertical section, and Fig. 101 a separate view of the solenoid escape-

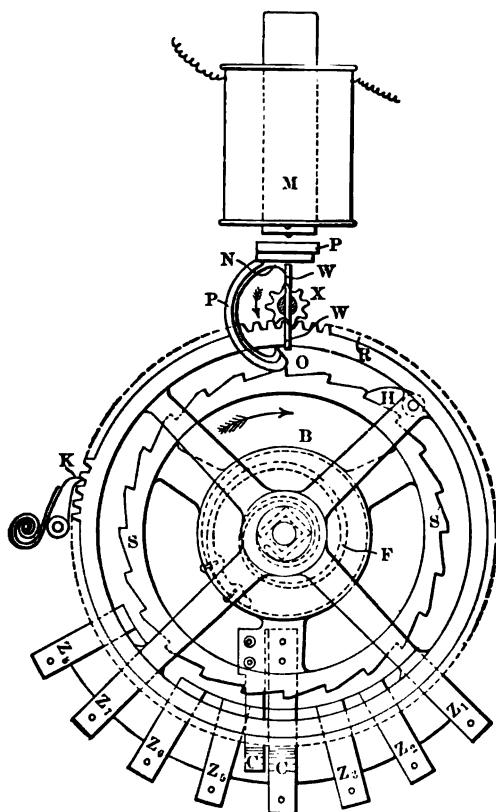


FIG. 99.

ment which controls the action of the switch. In the Figs.  $Z_1$ ,  $Z_2$ ,  $Z_3$ , etc., are contacts C and C', the double moving contacts joined by a resistance which is not shown here. K is a pawl held into the teeth of wheel R, by means of a spring. This wheel also meshes with a pinion X, which latter is unable to rotate unless the escapement N.P.O. is moved up or

down. The flat bar,  $W W^1$  is fastened to the pinion shaft and catches at one end or the other against one or the other of the escapement stops  $N O$  when this shaft rotates through a half circumference.

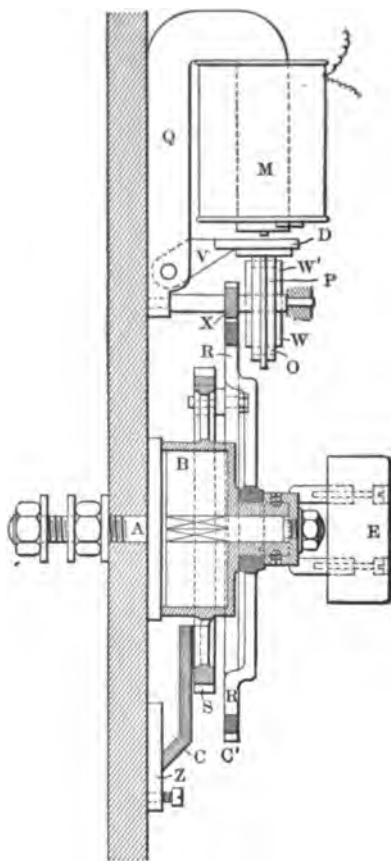


FIG. 100.

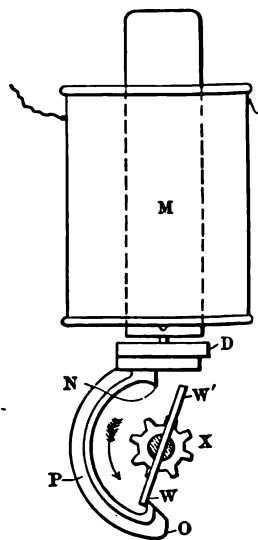


FIG. 101.

A ratchet wheel,  $S$ , the central portion of which is formed into a flat circular box,  $B$ , is mounted on the same shaft as  $R$ , but in a different vertical plane (see Fig. 100). Inside this flat, circular box is wound a heavy spiral spring,  $F$ , like a clock or motor spring, one end of which is fastened to the

circular box, and the other to the squared shank of the axle, A, around which both wheels turn. Obviously, if the wheel S, be turned backwards several revolutions by means of the hand wheel E, which is fastened to S, the spring will be wound up and tend to turn S in the direction indicated by the arrow. Pawl H, which is fastened to R, catches in the ratchets of S, and any motion of S in a clockwise direction is transmitted to R, moving it and the contacts C C<sup>1</sup>, which are joined to R.

The controlling magnet M, has a closed iron path Q V, which completes the magnetic circuit except the air gap between D and M. A joint allows V and D to vibrate.

When the magnet is excited by passage of current through its winding, D is lifted up and with it the escapement P. This allows the end W, of the bar or wing to pass escapement catch N, and the wheels S, and are rotated by the spring F, until the escapement catch O stops the motion of the pinion and therefore of the wheels (Fig. 101). The magnet winding circuit is now opened, and the escapement yoke falls to the position shown in Fig. 99, the half revolution of the pinion having been completed and the wheel R having moved just far enough to pass from one contact Z to the next.

The movement is controlled by a push button, which closes and opens the circuit through the magnet winding. It may be, however, made automatic by controlling the circuit through M with a contact voltmeter.

A type of automatic end cell switch manufactured by one of the American battery companies is shown diagrammatically in Fig. 102. M, is the armature of the motor, which is geared to the screw shaft of the end cell switch; f the motor field, S<sub>1</sub> and S<sub>2</sub> special forms of switches, T a push button which, when pressed, pushes down the rod i, and the pieces N and X mounted thereon. p, p<sup>1</sup> and h, h<sup>1</sup> are pairs of contacts connected together by N and X respectively, when these pieces touch the contacts, r is a spring which tends to push the rod and push button outwards, and normally holds X against h and h<sup>1</sup>.

S<sub>2</sub> consists of five contact points, a, b, c, d and e, spaced about a circle. W and W<sup>1</sup> are contact arms bent to the arc

of a circle. These are attached to a hand wheel and may be turned to connect different contacts together. In the position indicated by the full lines, a and e are connected, together, as are also c and d. By turning the hand wheel, which is not shown, being omitted to avoid complicating the diagram, the contact arms  $W W^1$  may be made to take the position shown by the dotted lines connecting d to e and b to c. The push button rod  $i$ , usually passes through

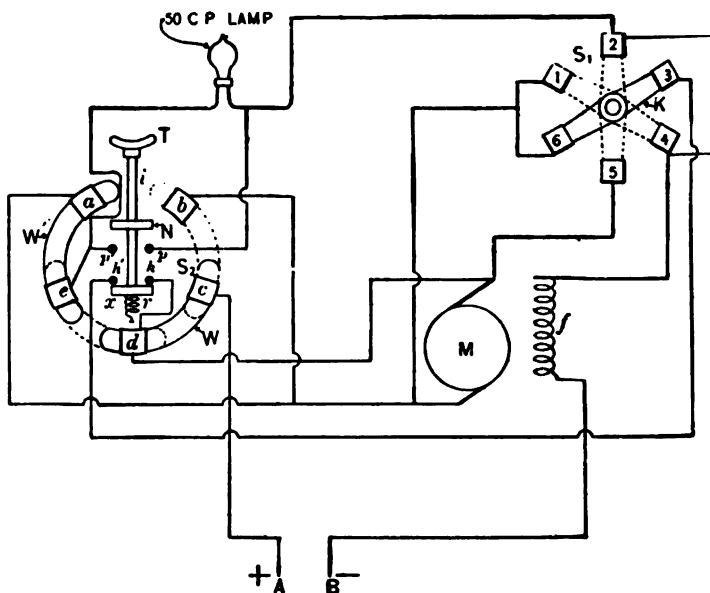


FIG. 102.

the centre of the hand wheel, the push button projecting above the latter.

$S_1$  consists of six contacts, 1, 2, 3, 4, 5 and 6, spaced about a circle. These contacts really form three pairs, and any pair may be connected together by the rotating arm  $K$ , which turns about a central pivot as shown. Normally, it is in the position shown by the full lines joining 1 and 4. As soon as the motor begins to run it changes to one of the positions shown by the dotted lines, this movement being automatically effected in a manner yet to be described.

A and B are the incoming mains from which current is taken to operate the switch.

M and  $S_1$  are at the end cell switch while T and  $S_2$  are on the switchboard. With the connecting arms of  $S_2$  in the position shown by the full lines, the motor can be started in a clockwise direction by pressing the push button T. Current flows continuously in the motor field f, the path being from A to c, to d, to h, to  $h^1$ , to 3, to 6, to a, to e, to  $p^1$ , through the lamp (which keeps down the field current) to 2, to 4, to f, to B. On pressing T, the circuit across h and  $h^1$  is opened, and p and  $p^1$  connected together. The path of the circuit now is A to c, to d, to M, to a, to e, to  $p^1$ , to p, to 2, to 4, to f, to B. That is; the current is passing through the motor armature and field in series, the resistance lamp being cut out. A strong field is produced and the motor starts. Immediately K rotates and joins 1 and 4. If the push button still be held down, the path of the circuit is as before, and also a parallel path from A to c, to d, to M, to 1, to 4, to f, to B. If the button be released, spring r returns it to its normal position, and the main path of the current through points last given is unchanged, only the auxiliary path through the push button contacts being opened. The motor, therefore, will continue to run after starting whether the button be held in position or released.

When the end cell switch contact shoe has moved such a distance as to register with the next succeeding contact point, the arm K swings to its normal position, joining 3 and 6, and if the push button be released before this point is reached, the connections are then such that a current flows through the motor field—passing through the lamp—and the motor armature is short circuited by the path M, 2, 3,  $h^1$ , h, d, M. This short circuiting in a magnetic field causes an instantaneous braking effect and stops the motor and switch at the proper point of shoe travel.

If the switch is to move in a reverse direction the motor must also rotate in a reverse direction. The hand wheel of  $S_2$  is turned so that  $W^1$  connects e and d, and W connects b and c. On pressing the button the motor will turn in a direction opposite to that in which it first rotated. On



starting, *k* turns and joins 2 to 5, and the connections are in effect the same as before, except that the polarity of the armature connections are reversed, as may be seen by tracing them out.

The mechanism which actuates *K* is shown in Fig. 103. *S* is the screw shaft of the end cell switch and *c* is a flat cam mounted thereon. *L, L*, is a T-shaped lever which is fulcrumed at *F*, as shown. *E* is a spring which tends to hold *L* in its normal position, which is as indicated by the full lines. *R* is a small roller at one of the ends of *L*, which runs

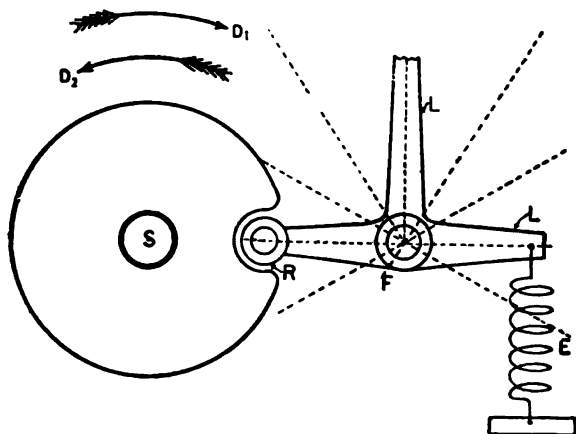


FIG. 103.

into the recess in the cam when a revolution is completed. The upper end of *L* is geared to the arm *K*.

The cam is so geared to the screw *s*, that when the contact shoe moves a distance equal to that from one contact to the next one adjacent, the cam makes one revolution.

On starting the motor, the upper end of *L* is thrown to the right or left, according to the direction of motor rotation and correspondingly turning *K*. When the revolution is completed, *R* is returned to its position in the slot by spring *E*, *K* is thrown to its normal position short circuiting the motor armature, and the rotation is instantly stopped.

Another excellent design is that of Dr. Paul Meyer, shown in Figs. 104, 105, 106, 107 and 108, and which may be applied

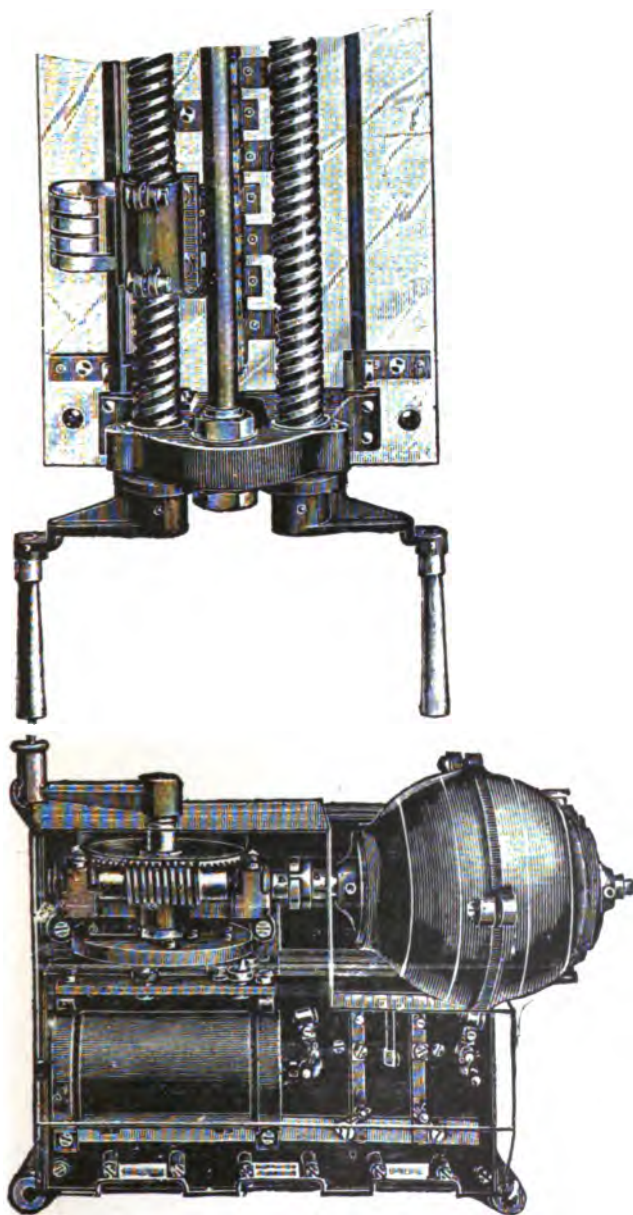


FIG. 104.

to any end cell switch that is operated by a crank or hand wheel.

Fig. 104 is a picture of the complete device, showing its application to a crank operated, vertically placed, end cell switch. As is seen, the machine consists of a crank, caused to turn by a small motor which transmits its power to the crank by means of a worm and worm wheel. Below the worm wheel and fastened to the same shaft is a disc.

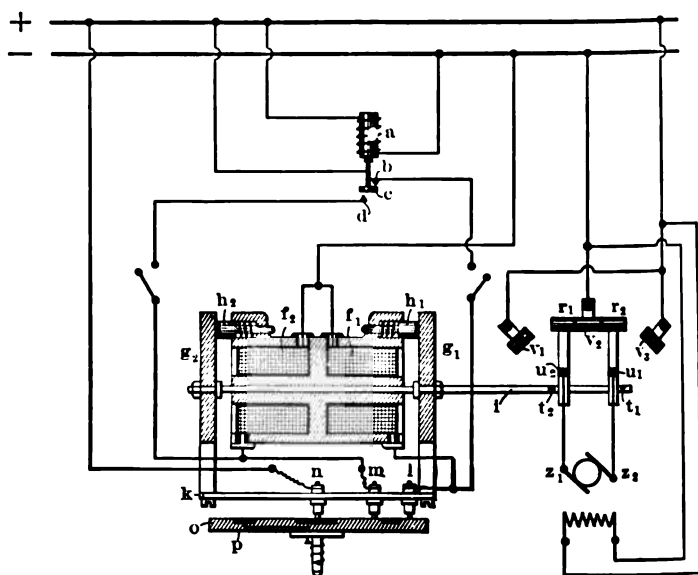


FIG. 105.

Underneath the disc is a straight bar, on which are mounted three contact points that touch against the lower surface of the disc. Below the bar is a solenoid or magnet, at either end of which is an iron cap, the iron caps being fastened to, and supporting the contact bar.

Underneath the motor may be seen other movable contacts, actuated by the straight bar which runs underneath the solenoid and which is also fastened to the iron caps at either end of the solenoid.

Fig. 105 shows, diagrammatically, the arrangement; a is

the voltmeter or potential controlled instrument which may be in the form of a solenoid or any other desired that is sensitive to 2 per cent. changes. It is connected across the line as shown, and actuates the contact piece *c*, which touches neither *b* nor *d* when the line voltage is normal. If the voltage rises, *c* closes against *b*, completing the circuit through the winding on the right hand end of the magnet *f*<sub>1</sub>, while, if the voltage falls, *c* closes against *d*, and the circuit through the winding on the left end of the magnet *f*<sub>1</sub>, is completed.

The iron plates, *g*<sub>1</sub> and *g*<sub>2</sub>, correspond to the end plates or discs at either end of the magnet referred to in Fig. 104. The disc, *o*, is shown below the magnet here, as is also the bar, *k*, carrying the contacts *l*, *m*, *n*. The rod, *i*, passing through the centre of the magnet corresponds to the bar

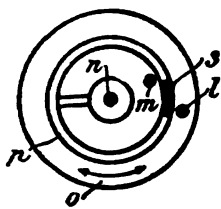


FIG. 106.

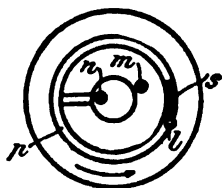


FIG. 107.

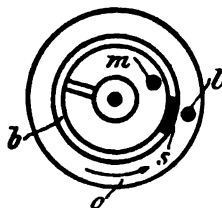


FIG. 108.

below the magnet in Fig. 104, which connects with the movable contacts *r*<sub>1</sub> and *r*<sub>2</sub>.

Figs. 106, 107 and 108 show the working face of the disc *o*, which is made of fibre or hard wood. A circular groove is cut in the face, and a flat copper ring sunk into it. This ring is not continuous but has a short segment removed and the space filled with hard wood, fibre or other insulating material, as indicated by the short black break in the ring.

A very small, thin disc of copper is also sunk into the surface of the large disc. The flat ring and the small disc are joined together by a connecting strip as indicated. The entire surface of the disc is smooth and the contacts which rest against it can slip lengthwise across its face and the disc can turn under them.

The action of this machine is as follows:

If the voltage should rise above normal, the voltmeter

contact would lift up, connect c and b and pass current through the magnet winding  $f_1$ , energizing the right end of the magnet and attracting the iron cap or disc at the right. This cap will be drawn over towards the left and in moving will shift with it both the contact carrying bar k, and the rod i, which latter is connected with  $r_1$  and  $r_2$ . At the time of making contact at c, the disc and disc contacts are in the position shown in Fig. 106, all the contacts being insulated from each other. When the contact bar moves to the left, the disc contacts take the position shown in Fig. 107. l and m are now connected through the copper parts and in addition to the circuit formed through b and c sending current through  $f_1$ , there is also another circuit made from n to l, which will allow current to flow through  $f_1$  until interrupted, regardless of the position which the voltmeter contact may take. The motion of the end cap towards the left also swings contact  $r_1$  over to the left until it touches  $v_1$ .  $r_2$  does not move and remains in contact with  $v_2$ . The connection is now made through the motor armature in such a manner as to cause a rotation of the worm wheel and disc in the direction shown by the arrow in Fig. 107.

This rotation must continue until one revolution has been completed, which will cause the end cell switch arm to move from one contact over the next one adjacent. When the single revolution is completed, the insulating piece s, passes under contact l and opens the circuit through the magnet winding  $f_1$ , which no longer being energized allows the spring  $h_1$  to push the iron cap g, back to its normal position. The motion of the motor should now cease as soon as rotation has carried the insulating piece s around just far enough for contact l to escape it, should the contact bar again move to the left. This stopping point is accurately adjusted by means of an electric brake, made by simply short circuiting the motor armature, which is done when contact  $r_1$  comes against  $v_2$ , which latter is already in contact with  $r_2$ .

It is seen that the three contacts, l, m and n are not in line, but l and m are spread or staggered the distance of this spread, being the length of the insulating piece.

If the potential of the line should decrease, contacts c and

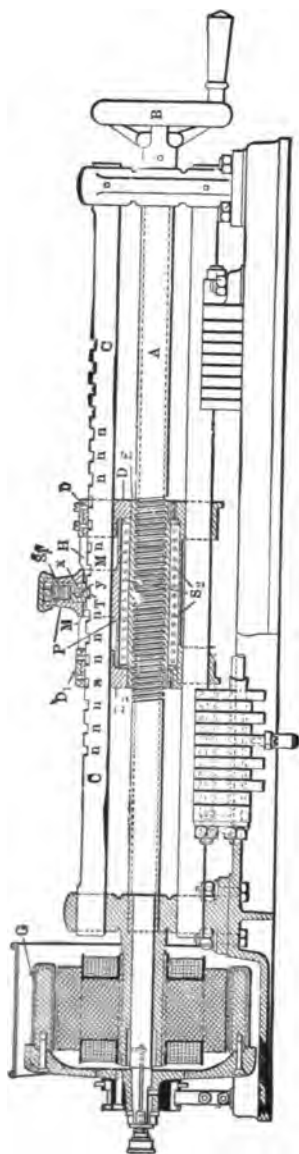


FIG. 109.

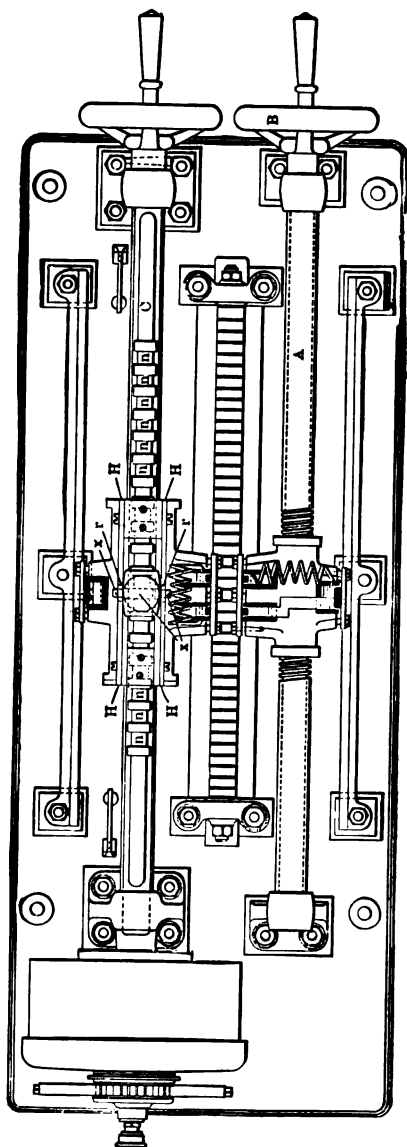


FIG. 110.

d would close;  $f_2$  being energized, the contacts all move toward the left, and the circuit through  $f_2$  made through m and n, the former now resting on the copper ring. Also  $r_2$  moves over to  $V_2$  and the motor armature is connected through them to the mains in a manner opposite to that in which it was connected when the magnet  $f_1$  was energized, consequently the action takes place in a reverse direction, the performance being in every other respect identical in the two cases.

The Schneider automatic switch depends for the positiveness of its length of travel on jumping a given distance when set in motion, and not on the continuous action of a screw thread or gear, which must make a definite number of rotations each movement. This switch is shown in Figs. 109 and 110.

Fig. 109 is a plan, and 110 an elevation.

In the figures, A is the moving screw; B a hand wheel for use when desired; G a motor on the opposite side with its armature keyed on to the screw shaft; C is a bar having notches, n, n, n, n, cut in it equally spaced along its length. When the catch T, at the end of piece X (Fig. 109), is in a notch, the moving contact registers with one of the contact points connected to the end cells. Surrounding the screw is the sleeve nut E, which is fastened to the two guides, D and  $D^1$ . These latter also surround the notched shaft C.

Attached to each side of the upper portion of the guides, and joining together D and  $D^1$ , are the flat bars H H, having a narrowed or recessed portion, the thinnest point being just beneath the small rollers rr and directly above a notch n, as shown.

When the screw rotates the nut travels, moving with it the guides and the bars H. The only connection, however, between the positively moved parts and the part P, is through the spring  $S_2$ , which is compressed when D moves and tends to urge P in the same direction though D may travel a considerable distance in either direction while P remains stationary.

P is held in position and restrained from moving by the tongue or pawl T, which forms the end of the piece X, and

engages in a notch on C. X is pressed always against the notched bar C by the small spring  $S_1$ .

Passing through X is a short axis y, which carries at its ends the small rollers r r.

The operation of this switch is as follows: When the motor is started the screw A rotates, moving with it the nut D, P meantime remaining stationary and the spring  $S_2$  becoming compressed. As H H move with D, the bevelled portions of these bars pass under the rollers r r, raising them and Y.

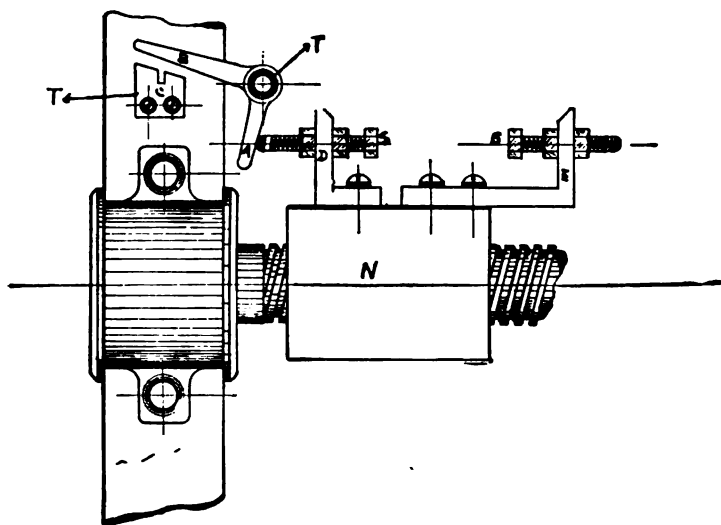


FIG. III.

When either of the points M has come under the rollers r r, the piece X has been lifted sufficiently to disengage the pawl T and the compressed spring  $S_2$  throws P along the same direction as travelled by E and D, and it overtakes them, the rollers running again over the hollowed part of the bars H H, and allowing the pawl T to catch into the next adjacent notch n on bar C. The end cell switch contact arm being directly connected to P, the movement from one contact to the next is positive and exact.

The motor may be started by a hand switch, or the device may be made completely automatic by applying a contact voltmeter or solenoid to close or open the motor circuit.



All automatic end cell switches must be provided with a safety device of some kind to prevent the jamming of the travelling nut on the screw when the end of its movement has been reached, at either end of the screw. One form is shown in Fig. III. N, is the travelling nut moving along the screw shaft. Fastened thereto are the pieces D and E, through which pass the adjustable screws S and S.

The current to the motor which rotates the screw passes through the arm B, of the bell crank lever to the clip C, and on through the rest of the circuit.

As N approaches the end of its travel, S presses against A, and causes B to rise, and leave the clip C, thus opening the circuit and stopping the driving motor. It is impossible for N to travel past a point which is fixed by adjusting S.

## CHAPTER XXIX.

### END CELL SWITCH INDICATORS.

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When end cell switches are operated by motors, it is desirable to know whether the contact arm has passed fully on to the proper cell contact and stopped without over-travelling. For this purpose end cell indicators have been devised which show at the switchboard the position of the contact arm. The most commonly used indicator is a straight scale over which a pointer travels, the motion being communicated from the end cell switch by means of small shafting and gears. This is a cumbersome appliance, but it is reliable and positive in its action.

A simpler and cheaper device which is also satisfactory, is made up of a small sprocket wheel at the end cell switch, and a sprocket chain passing over it, connected to a sprocket wheel on the indicator, which is also engaged by a sprocket chain. The chain is not continuous from the switch wheel to the indicator wheel, but the two short lengths are joined together by three-sixteenths of an inch steel wire rope, which can be turned over small guide pulleys in any direction. Turn buckles are inserted in both sides of the rope, so that accurate adjustment of the indicator pointer with relation to the position of the end cell switch contact arm is possible.

The end cell switch indicator shown diagrammatically in Fig. 112 and devised by A. S. Hubbard, operates electrically.  $G$  is the generator,  $12, 12^1$  two small slide bars;  $13, 13, 13^1, 13^1$  contact bars;  $11$  and  $11^1$  two contacts insulated from each other.  $1$  and  $3$  are iron rings wound with wire and connected as shown. Ring  $3$  is pivoted and has only one pair of tap points connected to brushes. It is evident that if current be passed through the brushes and winding, opposite magnetic poles will form at the points where the brush connections tap into the winding. Ring  $1$  is stationary, and

wound with wire, the winding being tapped at intervals around its circumference. The taps are lead to the contacts, 13, 13, 13<sup>1</sup>, 13<sup>1</sup>, the contacts opposite to each other being connected to diametrically opposite points in the winding.

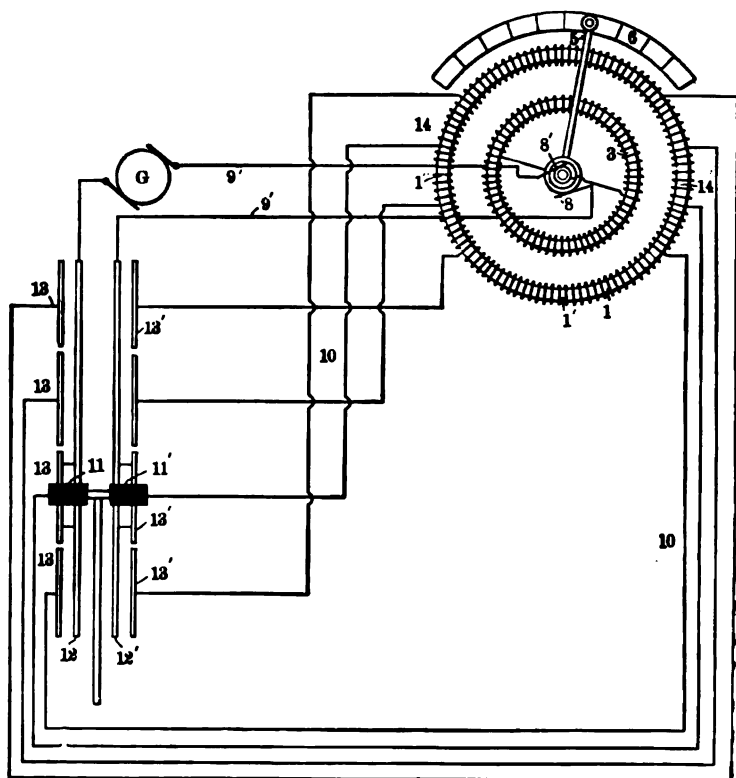


FIG. 112.

The angular spacing of taps is equal to the angular swing of the indicator in registering from one point to the next. The two contact shoes, 11 and 11', are attached to some moving part of the end cell switch and travel with the moving switch contact.

In the position shown, the circuit is from G to 11 out 13 to point 14<sup>1</sup>, where the current divides, part going around one side of the winding and part through the other, finally

leaving by tap 14 on the opposite side of the ring, thence to 13<sup>1</sup>, across to 12<sup>1</sup>, through to 8, passing through winding 3 and back to G from 8<sup>1</sup>. The ring 3 carries the pointer 5, which swings over the scale 6. Since 3 is pivoted it will always set itself in such a position that its polar axis will coincide with that of ring 1, and the polar axis of the latter changes with each change of contacts, 13 and 13<sup>1</sup>. Therefore, the instrument registers at any distance away from the end cell switch, the number of the contact on which the switch contact arm rests, and hence, the number of end cells in circuit.

It is made small and compact and consumes an inappreciable amount of energy in service.

## CHAPTER XXX.

### END CELL CONDUCTORS.

The conductors connecting the battery and end cells to the switchboard and end cell switches should have sufficient area for the current density not to exceed 1,000 amperes per square inch, when the battery is discharging at its maximum rate.

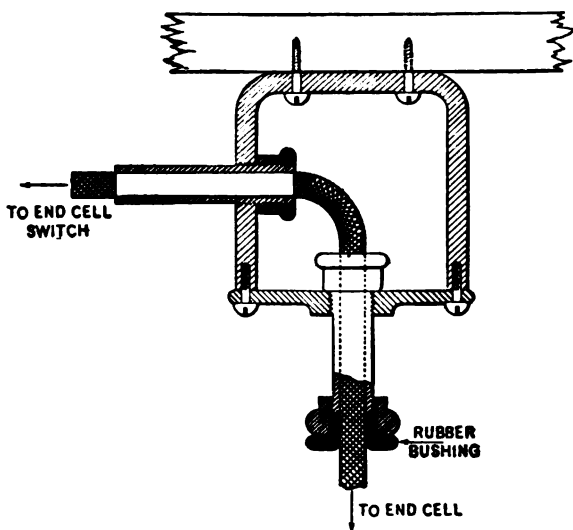


FIG. 113.

When installations are of small capacity, the end cell conductors are made up of insulated copper wire or stranded cable, these conductors are carried in shortest lengths to the end cell switch terminals, and connected thereto.

In many instances, the insulated wire or cable is simply run on insulators from the battery to the end cell switches located outside the battery room. When this is done, how-

ever, the insulation will soon deteriorate from the destructive action of the acid fumes; when the insulation becomes impaired, the bare copper is then exposed to the action of the acid. To prevent this the wires, when of small size, are sometimes laid in moulding, which is painted with some acid proof paint, such as black asphaltum.

A better method, however, and one that is applicable for

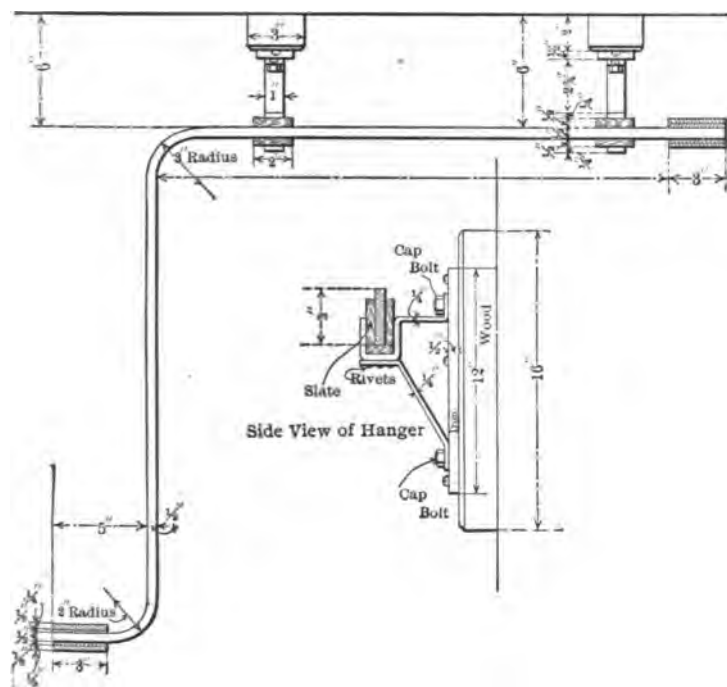


FIG. 114.

conductors of large area, is the use of iron conduit, which forms an effective and permanent protection for the cable.

When the conduit is used, it is better to have a separate duct for each end cell conductor. Each conduit outlet is situated directly over an end cell where the cable leaves the outlet box and the opening is provided with a soft rubber compression bushing to prevent any acid fumes from getting into the conduit as shown in Fig. 113.

If the maximum discharge of the battery exceeds 1,000 amperes, cable should not be used, rolled copper bars being

more satisfactory. No attempt is made to insulate these, but they are lead coated to prevent any corrosion by acid fumes. They are usually supported by hangers suspended from the ceiling. The hangers are provided with porcelain blocks which form an insulating support. Fig. 114 shows the method of supporting bar conductors.

The question of end cell copper has considerable bearing on the layout of the cells in the battery room. If the battery be of small capacity, the number of end cells conductor comparatively few, and if the end cell switch be located near the battery room, the layout demands no special attention in this regard. If, however, the capacity of the battery is such that copper bars must be used, it is then essential that the end cells be so arranged as to allow a minimum length of copper bar from the end cells to the end cell switch, and to have as few bends in the conductors as possible.

Where bar conductors are used, considerable accuracy is required in setting up the cells.

The bars are bent and drilled

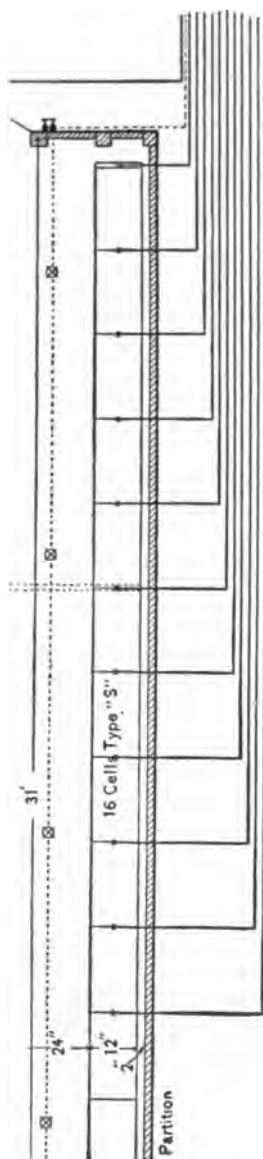


FIG. 115.

before shipment, consequently, if the tank and lead bus bar spacing are not exactly correct, the bolt holes will not register with each other and the separate runs of copper will not be parallel.

The cost of construction will vary, of course, with the amount of bending, drilling, etc., necessary, but an average figure of from 32 to 40 cents per pound will generally cover cost of bar work complete and erected.

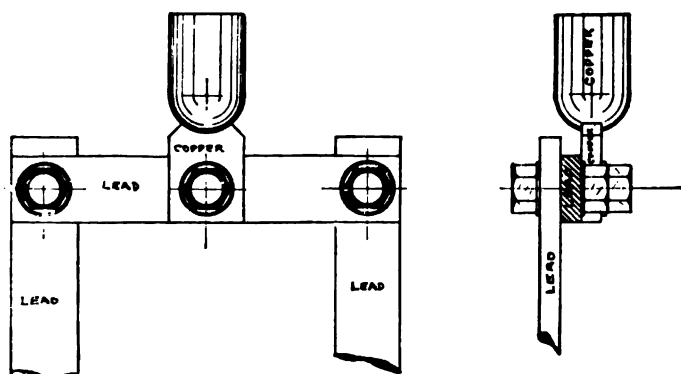


FIG. 116.

Fig. 115 shows arrangement of end cells for an installation using copper bar conductors.

Connections from end cell conductors to end cells are made with lugs where wire and cable are used. In the case of bar work, the conductor is bolted directly to the reinforcement of the lead bus bar.

Fig. 116 shows method of connecting wire or cable conductor to end cells, the cable being soldered into the lug, and this lug bolted to the cross bar between the two terminal straps.

All lugs, nuts and studs should be lead covered.



## CHAPTER XXXI.

### SHUNT AND SERIES BOOSTERS.

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Boosters are dynamo electric machines which are placed in series with the battery or with the supply line to the bus bars, across which the battery is directly connected. The function of these machines is to generate an E.M.F. assisting the flow of current from the main generator to the battery or an E.M.F. opposing that of the main generator and assisting the battery to discharge. This added or subtracted E.M.F. may compensate simply for the drop due to the internal resistance of the battery and connections, or the change in battery voltage as the state of charge is changed, or both.

Boosters may be hand controlled or automatic, in their variation of E.M.F., to meet changed conditions of battery charge or drop. They may be classified as self-excited and separately excited. Under the first are grouped the shunt, series, compound, differential and constant current, the last named being a differential machine but termed "constant current" because it allows only an (approximately) unvarying current to pass through its armature. All automatic boosters are designed to be constant current machines in the sense of limiting the generator output to a constant value, although the current through the booster itself may be widely variable, excepting in the case of the so-called, constant current machine.

The shunt booster\* is used to augment the generator voltage in charging a battery which is to be later discharged in parallel with the generator, or which may carry the entire load along.

Consider the case of a 110 volt circuit with a battery which is to carry the light load, or work in parallel with the

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\*Patent 435,700 to H. W. Leonard.

generator on heavy load. The voltage at the end of discharge will be 1.8 volts per cell, and therefore  $\frac{110}{1.8} = 61$

cells will be required. The voltage per cell at the end of charge, however, will be 2.6, and the total voltage  $2.6 \times 61 = 159$  volts, which is 49 volts more than the generator E.M.F., and this is the voltage that the booster will have to furnish.

This machine may also be used reversibly—that is, give an E.M.F. to assist the battery to discharge—when excited from the bus bars, and provided with a reversing rheostat. In this case it will assist the battery to discharge when the direction of the field magnetization is changed. When so used, no end cells are necessary, but the booster must be run continuously during the entire period of discharge. On a 110 volt circuit, 56 cells will be sufficient with a reversible booster. Voltage to charge fully is  $56 \times 2.6 = 146$  or 36 volts above generator voltage. Minimum voltage of discharge  $= 1.8 \times 56 = 100$  volts or 10 volts less than that of the line. Therefore, the booster need give only 36 volts maximum, and is called on to add 10 volts to the battery voltage toward the end of battery discharge. In this case, the booster

voltage is only  $\frac{36}{49}$  or three-fourths that required in the pre-

ceding case; five cells less of battery are necessary and the end cell switches and leads are eliminated.

The machine will be much larger, however, than it would be if used only for charging, because the discharge current is invariably greater than that of charge, and the current carrying capacity of the armature must be great enough to take care of the heaviest currents.

Fig. 117 shows the usual connections of a non-reversible shunt booster and battery system.

G is the main generator, B the booster,  $S_1$  a double-pole, single-throw switch,  $S_2$  and  $S_3$  single-pole switches,  $S_4$  a single-pole, double-throw switch, and  $S_5$  a battery and cell switch.

To charge,  $S_1$ ,  $S_2$  and  $S_3$  are closed;  $S_4$  is closed down-

ward and  $S_6$  put on the fifth or last point. Part of the generator current will go into the line and part through the booster into the battery. Charging current is adjusted by means of rheostat  $R$ , which varies the e.m.f. of booster.

To discharge, open  $S_2$  and throw  $S_6$  to first point on end cell switch. Next,  $S_4$  should be thrown over to the upper clip. The battery is then in parallel with the generator with all end cells cut out. As the e.m.f. of the battery falls, end cells are cut in by switch  $S_6$ . When  $S_2$  is opened, the batteries supply the entire load.

In the case of a reversible booster, the booster field is

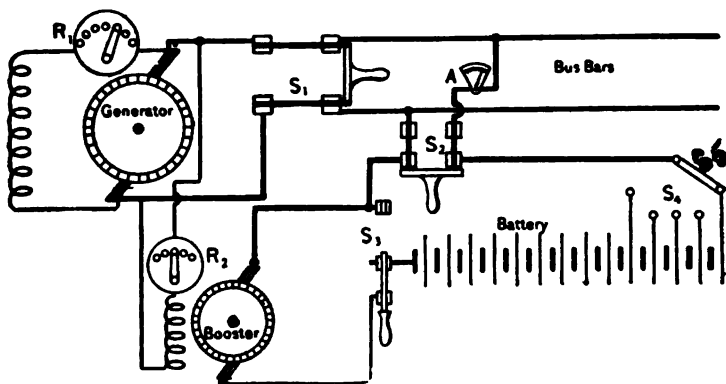


FIG. 117.

connected across the bus bars and a reversing switch or rheostat is used, the end cells and  $S_6$  being cut out. The size of booster required varies with the voltage of the system, and the maximum rate of current flow. If the maximum lasts only a few minutes, it may be considered as overload and the machine designed for a normal load, less than that represented by the maximum.

The maximum voltage should be equal to  $2.75 \times N$  where  $N$  is the number of cells in series. The voltage of 2.75 per cell is sometimes necessary in giving the battery an overcharge.

The power of the driving motor is seldom made equal to the K.W. capacity of the booster. Since the maximum booster voltage and current never occur simultaneously, the

maximum K.W. capacity is never reached, and there is no need of making the motor sufficiently large to handle this rated capacity of the booster.

If the booster is reversible, the greatest driving power will be required when the maximum discharge is given out and the voltage of the battery lowest. For instance, if the normal charging rate is 50 amperes and there are 56 cells in the battery which is connected across a 110 volt circuit, the maximum power to drive when charging, would be when the voltage per cell reached 2.6 volts. The booster volts at this time would be  $2.6 \times 56 - 110 = 36$  volts. Assuming the current of overcharge to be one-half the normal, the booster

$$\text{Watts} = 36 \times \frac{50}{2} = 900.$$

$$\text{Motor H. P.} = \frac{900 \times 1.34}{.75} = 1.61 \text{ H. P., } .75 \text{ being the as-}$$

sumed efficiency of the booster. If, however, the maximum discharge rate is 180 amperes, and the battery voltage is 1.8 per cell, the booster volts are equal to  $110 - 56 \times 1.8 = 10$  volts.

$$\text{Motor H. P.} = \frac{10 \times 180 \times 1.34}{.75} = 3.23 \text{ H. P.}$$

which is as large as the motor should be made.

The size of the booster would be  $36 \times 180 = 6.5$  kilowatts, unless the maximum amperes flowed only for a few moments, in which case the capacity could be somewhat reduced. If the booster were used only for charge, there would have to be 61 cells in series, making the booster maximum voltage on charge = 49 volts. The capacity would be  $49 \times 50 = 2.45$  K.W.

These figures show the increase in size of booster and motor when the former is made reversible, though the computed increase is for the particular conditions given only.

A method of connecting up a shunt booster and its driving motor that is sometimes used in Germany, is shown in Fig. 118.

G is the generator, L and L' mains, M the driving motor, and B the booster.  $f_1$  and  $f_2$  are the fields of motor and booster respectively, connected in parallel from L to L', through rheostat R, as indicated. As the rheostat lever is moved across the contact buttons, one field is increased while the other is decreased. Thus, in the position shown in the figure, the motor field is strong, while the booster field is weak, resulting in a low booster E.M.F., due both to its weak field and the slow motor speed, which latter results from its strong field. With the arm in the position shown

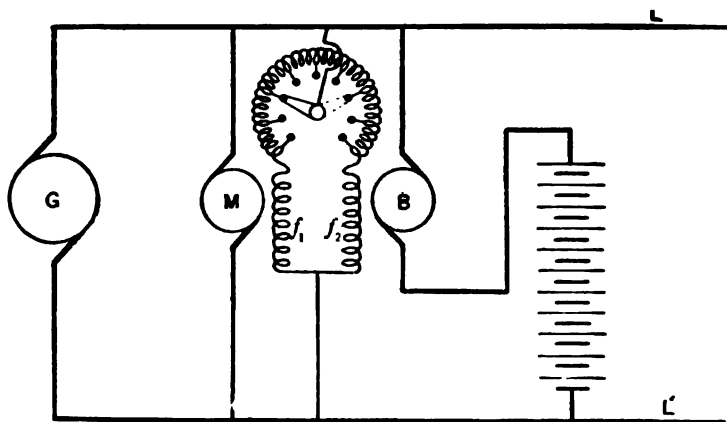


FIG. 118.

by the dotted lines, the converse of the foregoing condition will obtain.  $f_1$  becoming weak and  $f_2$  strong, giving a high motor speed and strong booster field, and a resulting high booster E.M.F. This method does not seem to offer any advantage over the ordinary motor driven booster in which rheostats are inserted in the field circuits of both machines.

H. W. Leonard's patent of September 2, 1890, also covers the use of series-wound machines as boosters. The connection to the battery is the same as that of the shunt booster, *i. e.*, machine and battery in series and connected across the line. With no current flowing into or out of the battery, the e.m.f. of booster is zero.

Should the voltage on the line rise because of a decrease

of load and a charging current go into the battery, the booster will give an e.m.f. tending to send more current in. The reverse conditions occur when discharge takes place. The series booster acts so as to compound the battery, and tends to maintain a constant e.m.f. on the line, whatever the load may be. It depends for its operation on the fact that the generator voltage must rise and fall with the load, and therefore can be used only with a shunt dynamo or its equivalent as the source of supply. This system is suitable only for power work, and is analogous in its operation to the case of the "floating battery." It is not commercially used, as other types give better service, under the same conditions.

It may be noted, however, that the series booster is automatic and adjusts its E.M.F. to produce the proper rate of discharge or charge with varying external load, and it also tends to maintain a constant E.M.F. across the line, under all conditions of change in circuit.

## CHAPTER XXXII.

### THE COMPOUND BOOSTER.

The compound booster is used on railway and power circuits supplying widely fluctuating loads where the batteries serve to prevent excessive feeder drop, and assist the power station, relieving the generating machinery from the sudden heavy current rushes. Diagrammatically, this system is shown in Fig. 119.

G is a generator, E a battery, B the booster armature, F

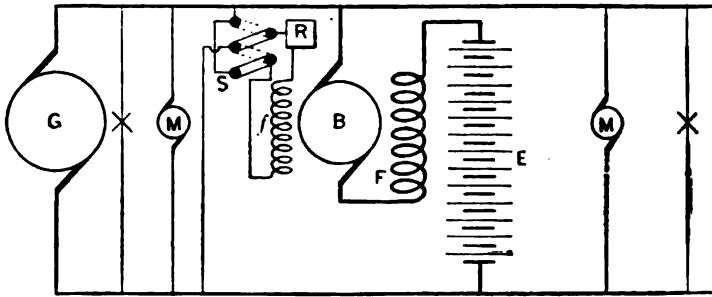


FIG. 119.

a series field,  $f$  a shunt field,  $R$  a rheostat in shunt field circuit,  $M$  and  $M$  motors, and  $S$  a reversing switch by means of which the m.m.f. of the shunt field may be added to or subtracted from that of the series field. The operation of this system is as follows:

Under normal conditions the shunt field m.m.f. creates an e.m.f. in the same direction as the battery e.m.f. tending to discharge it. Calling  $E_g$  the generator e.m.f.,  $V$  the booster e.m.f., and  $E_b$  the battery e.m.f., we have  $E_g - V = E_b$  (24), when there is neither charging nor discharging current. In this case the generator current equals the external load cur-

rent. If the load increases  $E_0$  falls, and  $E_A + V$  becomes greater than  $E_0$ , allowing the battery to begin discharging. The discharge current passing through the series coil produces an e.m.f. proportional thereto, and acting with the shunt coil, thereby increasing  $V$  and increasing  $E_A + V$ , causing a still more rapid discharge. The battery thus assisting the generator, causes the load on the latter to decrease and its voltage to rise again until it attains its normal e.m.f.

If the load on the external circuit falls below normal,  $E_0$  rises and current starts flowing into the battery. In this case, the series field m.m.f. opposes that of the shunt coil, decreasing  $V$ . Then  $E_0 > E_A + V$  and the charging current increases until  $E_0$  begins to fall, and comes down to its normal value. These changes are, more strictly, tendencies to change which are checked in their inception.

In order to compute the size and windings of the booster a load curve is necessary. This, in case of a new plant, may be made up from assumed data, which, with the amount of data available covering operating plants similar to the proposed plant, will usually be sufficiently accurate to use as a basis for computation.

The armature and series coil must have a current carrying capacity equal to the maximum battery discharge, or  $I_x = I_0$ , in which

$I_0$  = generator current.

$I_x$  = current of external load.

Also let

$I_A$  = normal external load, equal to average load.

$E_m$  = generator voltage at no load.

$E_A$  = battery voltage at any state of charge (voltage on open circuit).

$E_N$  = normal battery voltage.

$h$  = constant which multiplied by the generator current equals drop in generator e.m.f.

$R$  = virtual internal resistance of battery.

$k$  = volts generated in armature per ampere turn on field.

$N$  = number of cells in series =  $\frac{E_A}{2}$ .



The series turns compensate for the drop due to resistance of the battery circuit. Therefore

$$T k I = R I \text{ and } T = \frac{R}{k} \dots \dots \dots (25)$$

$I$  being the current flowing into or out of the battery. In this equation the characteristic of the booster is assumed to be a straight line. The factor  $k$  also assumes a constant permeability.

When  $I_0 = I_x$  current flows neither into nor out of the battery, and

$$E_M - I_0 h - V = E_A \dots \dots \dots (26)$$

Inasmuch as the booster causes the battery to act as if it had no internal resistance, the only factors that enter into the determination of  $I_0$  are  $V$ ,  $E_A$ ,  $E_M$  and  $h$ , or,

$$I_0 = \frac{E_M - V - E_A}{h} \dots \dots \dots (27)$$

These are all constants and, therefore,  $I_0$  is constant for any given value of  $E_A$ , whatever the load, provided the shunt coil is connected across the mains and gives a constant m.m.f.

If, however, the shunt coil is connected across the battery terminals, equation (27) becomes

$$I_0 = \frac{E_M - \frac{V E_A}{E_N} + I_x \frac{R V}{E_N} - E_A}{h + \frac{R V}{E_N}} \dots \dots \dots (28)$$

This shows that the generator current varies with the load if  $f$  be connected across the battery. The factor  $\frac{R V}{E_N}$  is, however, usually very small as compared with the other quantities.

If  $V$  be made small,  $E_A$  more nearly approaches  $E_M - I_0 h$ , and the size of the machine is kept down. If  $V$  be made

large the size of booster is increased, but the number of cells decreased.

Generally,  $V$  at normal voltage of battery should be small — 0 to 5 volts. The shunt coil, however, must be capable of producing an e.m.f. high enough to maintain the equality of (26) when  $E_A$  is at its minimum, and also to preserve the equality of

$$E_M - I_0 h + V = E_A \dots\dots\dots (29)$$

when  $E_A$  is at its maximum and the field is reversed in direction, the booster adding its e.m.f. to the generator e.m.f.  $E_A \text{ max} = 1.15 \times E_A$ , or  $V \text{ max}$  must equal  $.15 E_A - V$  when  $f$  is connected across the line and  $\frac{.15 E_A}{1.15} - V$  when  $f$  is connected across the battery.  $V \text{ max}$  for  $E_A \text{ min} = 0.1 \times E_A \times V$  for connection across the line, and  $\frac{.1 \times E_A}{.9} \times V$  for connection across the battery.

These data fix the shunt winding, and together with eq. (29), the size and resistance of the rheostat. This latter should be capable of varying the shunt coil e.m.f. from 0 volts to maximum by steps of not over 2 volts each.

The size of the motor is fixed by the maximum of voltage multiplied by the current, both being taken at the same instant. This product is a maximum when the battery is at its lowest voltage, and discharging its maximum current.

Assuming 1.8 volts per cell as a minimum,  $E_A \text{ min} = \frac{E_A \times 1.8}{2} = .9 E_A$ . The voltage then of booster when dis-

charging  $I \text{ max} = 0.1 \times E_A + (I \text{ max } T k) + V$ .

Watts =  $I \text{ max} (0.1 \times E_A + I \text{ max } T k + V)$  = size of driving motor.

This form of booster can also be connected for normal operation with the shunt coil e.m.f. in opposition to the battery e.m.f., in which case

$$E_M - I_0 h = E_A - V \dots\dots\dots (30)$$

and the required number of cells in series is greater than when connected with  $V$  opposing the generator e.m.f.

The relations of the various quantities can easily be worked out from the equations given by making the proper substitutions of signs. In this case

$$I_0 = \frac{E_M + \frac{V E_A}{E_N} - I_x \left( \frac{R V}{E_N} \right) - E_A}{h - \frac{R V}{E_N}} \dots \dots \dots (31)$$

The equation shows that connected in this way the generator load varies inversely as the external load. This would put too great a load on the battery at the time of maximum discharge.

As a concrete example, illustrating the application of the foregoing analysis assume

$$\begin{aligned} E_M &= 500 \text{ volts.} \\ V &= 10 \text{ volts.} \\ h &= 0.15. \\ I_0 &= 100 \text{ amperes normal.} \\ I_x &= 400 \text{ amperes maximum.} \\ R &= .2 \text{ ohm.} \\ k &= .02 \text{ volt.} \\ E_A &= 500 - (100 \times .15) - 10 = 475 \text{ volts.} \\ T &= \frac{.2}{.02} = 10 \text{ turns.} \\ N &= \frac{475}{2} = 238 \text{ cells.} \end{aligned}$$

with any given values of  $E_A$  and  $V$ ,  $I_0$  will remain unchanged whatever may be the variation of  $I_x$ .

If  $E_A$  varies and  $V$  be not varied to compensate therefor,  $I_0$  will vary, but will be independent of the external load.

When  $E_A + V = E_M$ ,  $I_0$  reduces to zero and the battery carries the total external load.

When  $E_A$  is a minimum,  $I_0$  is greatest if  $V$  remains constant.

$$I_0 (\text{maximum}) = \frac{500 - 10 - 427.5}{.15} = 416 \text{ amperes.}$$

Of course, this is an abnormal current that might occur under extraordinary conditions, but  $E_A$  could never fall to 427.5 volts without manipulation of the rheostat, which would leave the system in an approximately proper condition to make the battery take its share of the load.

The calculations for  $I_0$  when the shunt coil is connected across the battery, may be made by substituting in eq. (28).

$$\text{In the example assumed, } I_0 = \frac{500 - 475 - 10}{.15 + \frac{.2 \times 10}{475}} = 97.4 \text{ amperes,}$$

when  $I_x = 0$ ; with  $I_x = 100$ ,  $I_0 = 100$  amperes; and for  $I_x = 400$ ,  $I_0 = 108$  amperes. The regulation is better with the shunt coil connected across the line.

When  $E_A$  rises, and  $V$  is not reversed, the battery tends to take all the external load. Therefore, conditions may occur under which  $I_0$  will fall as low as 50 amperes, while  $I_x = 400$ . The carrying capacity of the booster armature and series coil should be 350 amperes for, say, 10 minutes.

The maximum voltage that the shunt coil can produce is the greater of two maxima; the one when  $E_A$  is maximum, and the shunt coil reversed acting to *prevent* discharge; the other when  $E_A$  is minimum.

$$V_1 \text{ max for } E_A \text{ max} = 475 \times .15 - 10 = 61.25 \text{ volts.}$$

$$V_2 \text{ max for } E_A \text{ min} = 0.1 \times 475 + 10 = 57.5 \text{ volts.}$$

The shunt coil, therefore, with all resistance cut out, must be capable of producing 62 volts.

The booster voltage is maximum when  $E_A$  is at its minimum and  $I_x$  maximum, and is equal to  $(V_2 \text{ max} + I \text{ max } T k)$ , in which  $I \text{ max} = I_x \text{ max} - I_0$ . This is  $57.5 + .2(400 - 100) = 117.5$  volts. The maximum booster and driving motor capacity is  $117.5 \times 300 = 35.25$  kw.

As the maximum is seldom reached and then lasts only a few moments, about 70 per cent. of the calculated capacity would be great enough, or 25 kilowatts in the above case.

$$\text{The motor horse-power is } \frac{25}{.746 \times .90} = 37.2 \text{ h.p., } .90 \text{ being}$$

the efficiency assumed for the booster.

Fig. 119 shows that the load may be connected to the line

either between the booster and the power station or between the booster and extreme end of the line. The battery and booster may therefore be located on a railway feeder at the point of greatest drop. The battery may also be made to help the power station on the peak of the load by manipulating the rheostat as  $E_A$  falls.

This system, depending as it does on the rise and fall of generator e.m.f. with corresponding change of load, requires that the generator be a shunt machine or its equivalent.

Where a plant has in operation a generating equipment of

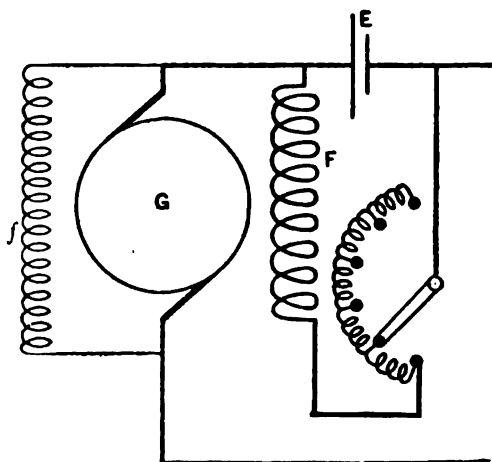


FIG. 120.

compound-wound dynamos, and this booster and battery system is applied, some change must be made in the generators. If the series field be entirely cut out, the dynamo will not generate the normal e.m.f. at normal load. In order to make use of the existing machines and windings, the arrangement shown in Fig. 120 is resorted to.

In this diagram  $G$  is the generator,  $f$  and  $F$  its shunt and series fields, respectively,  $E$  a low-voltage accumulator—usually one or two cells—and  $R$  a variable resistance in series with the series field circuit. The battery is connected in multiple with the series coil and resistance  $R$ , as shown. When the load on the generator is normal, the drop through

$F + R$  is equal to the battery e.m.f. If the generator load rises  $(F + R) I_0$  is greater than the battery e.m.f., and the current divides, part going through the battery and the normal current going through  $F + R$ . Should the load decrease and battery e.m.f. be greater than  $(F + R) I_0$ , the battery discharges and sends the normal current through  $F + R$ . The variation in  $I_0$  will be small, owing to the regulating effect of the main battery and booster on the line.

Since, with this arrangement, the generator excitation is the sum of a constant excitation and an excitation that varies inversely as the load, its characteristic will be similar to that of a shunt machine.

From the foregoing description it will be seen that the compound booster is automatic within certain limits of battery charge. Any marked change of battery voltage will be followed by a corresponding change in generator current, unless the rheostat be manipulated to bring  $E_A + V$  back to normal.

While the theoretical generator current variation is small for a given change of load, there is always a sudden, momentary, current rush from the generator on increase of load, the duration of which is equal to the time lag of magnetization of the booster field. Lights on a circuit with variable load will "wink" on sudden changes of load. In this respect the compound booster is not so satisfactory as the constant-current booster, as in the latter *all* generator current passes through the series fields, which, by reason of their self-induction, oppose and check any sudden current rush, giving the booster field time to change its magnetization to the proper degree.

The compound booster system, together with the described arrangement of compound generator is covered by patent No. 625,099, issued on May 16, 1899, to J. B. Entz. This patent also covers the use of a series booster without shunt field, which is the same as H. Ward Leonard's patent, No. 435,700, of September 2, 1890.

Since boosters usually carry heavy currents at low voltages, the commutator and brush surfaces necessary are often much larger than in the case of standard dynamos. In order

to make use of standard commutator segments, to keep the length of the brush holders down to standard and keep the commutator speed within the limits of good practice, double commutators are sometimes used. These are placed, one on either side of the armature, and are connected in parallel or series, as required.

This arrangement permits of a reduction in the size of the booster, for the reason that the maximum voltage is usually fixed by the battery E.M.F. when it is being "boiled" or overcharged. On overcharge, however, only a small current is desired, so, on such occasions, the two commutators may

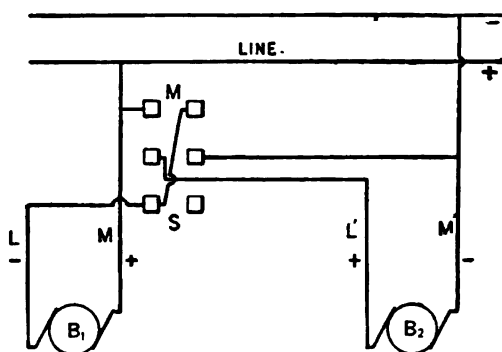


FIG. 121.

be connected in series and a lower voltage—and consequently smaller—booster may serve. In addition to the reduction in size of the booster which is affected by the double commutator machine, the booster efficiency is markedly increased. The efficiency of a booster which works under widely varying loads would be very small if it were not for the fact that the voltage of the machine also varies, and the efficiency is very similar at different loads to that of a series wound dynamo. Since the principal losses in small machines of this type are the iron losses, it is desirable to keep the size down as small as possible, which is effected by the double winding and commutators.

The leads from the brushes are carried to a double pole, double-throw switch, which, when thrown in one direction,

puts the circuits in parallel, while on the other contacts the circuits are in series. Fig. 121 shows this method of connecting; L.M. is the pair of mains from one commutator, and  $L^1 M^1$  similar mains from the other

The current in any case goes to the battery by L and  $M^1$ . From the diagram it is evident that when the switch is on the upper position the two circuits are in parallel, and when the switch is thrown downward, the circuits are in series.



## CHAPTER XXXIII.

### THE DIFFERENTIAL BOOSTER

The differential booster is used on power and railway circuits where the load fluctuates widely and suddenly. There are several varieties of this type of booster, and many patents have been issued covering the different methods of varying the e.m.f. of the machine. Some of these patents

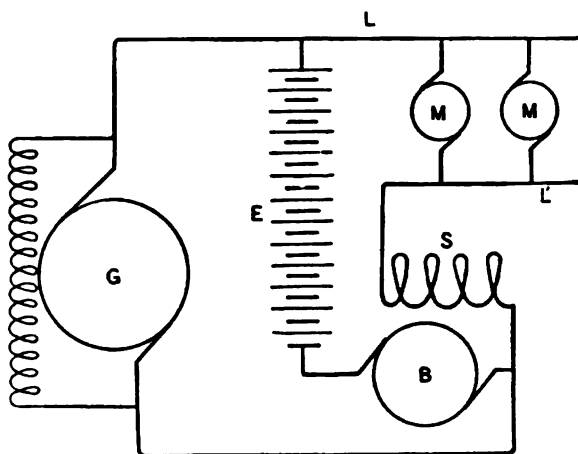


FIG. 122.

appear to be identical with each other and lead to doubt as to the efficiency of the United States Patent Office.

The first automatic booster patent issued, was granted to C. O. Mailloux, June 24, 1890, under number 430,868. This patent covers the booster system shown diagrammatically in Fig. 122, and, in connection therewith, as a modification of the basic patent, a differential booster.

The original patent contemplates a battery E in series with a booster armature B. This combination is connected

across the mains  $L$ ,  $L^1$ , the generator  $G$  being the source of supply. The total current supplied to the line passes through the series field  $S$  on the booster. It is evident that within the limits of saturation the e.m.f. of the booster will vary directly as the external load. This e.m.f. is opposed to the generator e.m.f., and tends to discharge the battery. When the load is light the booster e.m.f. is low and the generator e.m.f. overcomes it and the battery e.m.f., and sends a charging current into the battery. At normal load the series field produces an e.m.f., which, added to the battery e.m.f., balances the generator e.m.f. and current flows

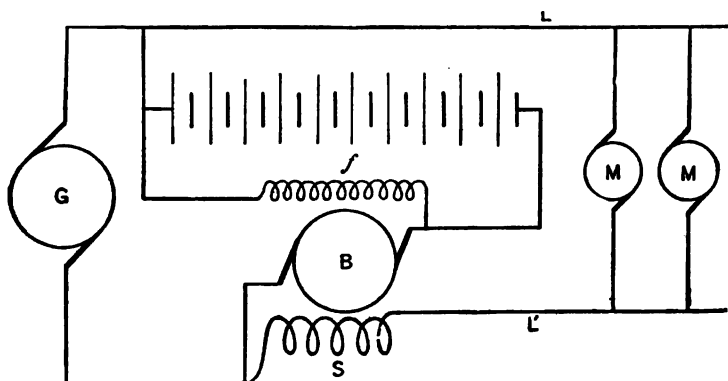


FIG. 123.

neither into nor out of the battery. A load greater than normal raises the booster e.m.f., causing it to discharge the battery at a rate proportional to the external load.

The differential booster which appears in this same patent is as shown in Fig. 123. In this the shunt coil  $f$  opposes the series coil  $S$ , tending to produce an e.m.f. in the same direction as the generator e.m.f., and to send current into the battery. At normal load the series and shunt coils balance each other, the e.m.f. of the booster is zero, and current flows neither into nor out of the battery. A heavy load causes the series to overpower the shunt field, and the e.m.f. of the booster is in such a direction as to discharge the battery. A load lighter than normal allows the shunt to overpower the series field, and the booster e.m.f. is added

to the generator e.m.f., causing a charging current to flow into the battery.

Patent No. 589,186 granted to Meredith & Hunt, on August 31, 1897, appears to be identical in every respect with the differential booster system patented by Mailloux in 1890.

The differential booster commonly used is a modification of that of Mailloux, and was patented May 16, 1899, under No. 625,098, by J. B. Entz. This system is explained by Fig. 124.

G is the generator, B the booster armature, E a battery,

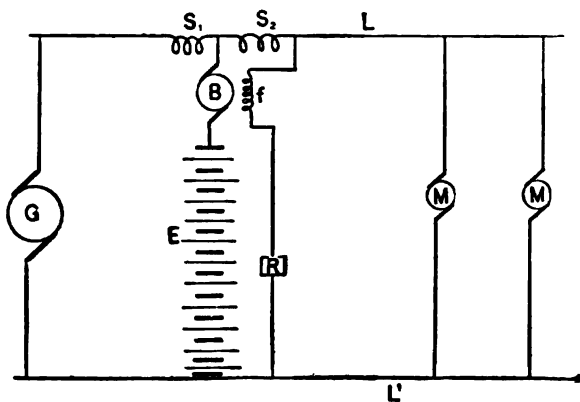


FIG. 124.

*f* the shunt field of the booster connected across the battery terminals, S<sub>1</sub> and S<sub>2</sub> series fields, L, L' the mains and M, M, the external load.

As shown, S<sub>1</sub> is in series with the generator and carries all current supplied, and at the rate at which the generator furnishes current. S<sub>2</sub> carries all current supplied to the external circuit, which at any time, is equal to the algebraic sum of the generator and battery currents, when the generator and discharging currents are taken as positive and charging current as negative.

S<sub>1</sub> and S<sub>2</sub> act together to produce a m.m.f. opposed to that produced by the shunt field. As the object of this system is to maintain a constant load on the generator, S<sub>1</sub>

may be considered as constant. The field then due to  $f-S_1$  is constant. If at normal load  $(f-S_1)-S_2=0$ , the booster e.m.f. will be zero, and there is neither charge nor discharge. As  $S_2$  varies directly with the external load, an increase or decrease will result in a booster e.m.f. acting to discharge or to charge the battery. This action is, in fact, the same as that of Mailloux's differential booster, considering  $(f-S_1)$  as the equivalent of the opposing shunt field of Mailloux's system.

The reason of the application of  $S_1$  lies in the fact that any considerable variation in the battery e.m.f. will disturb the equilibrium of the system unless this compensating coil is used. If the e.m.f. of the battery be lower than normal, it will not discharge rapidly enough to relieve the generator of overload fluctuations unless the booster e.m.f. be increased, and the generator will therefore have to supply a current greater than its normal capacity. If, however, a current greater than normal flows through the coil  $S_1$ , the value of  $(f-S_1)$  is reduced, and  $S_2$  still further overpowers the resultant of those two and causes a higher booster e.m.f. tending to discharge the battery, and thus bringing down the generator load to normal. Should the battery e.m.f. be above that it ordinarily has, the reverse operation will take place; the battery tending to discharge too rapidly will be brought down and the generator allowed to take its share of the load, because of the booster e.m.f. being lowered by decreased current in  $S_1$  due to light load on the generator.

This system is entirely automatic with the exception of occasional variations in the strength of shunt field  $f$  effected by means of rheostat  $R$  to compensate for changes in the battery e.m.f. It is adapted for systems supplying both light and power, where the lighting mains are connected to  $L$  and  $L_1$  between the booster and the generator forming a non-fluctuating load.

The fluctuating load must be connected to the mains *after* they pass through their proper booster connections.

In the compound booster system, it will be remembered, power can be taken from either side of the booster connections.

As in the case of the compound booster, the battery may be made to help the generator carry the peak of the load as well as take up the fluctuations. This booster will operate satisfactorily with a compound-wound generator as the source of supply. In calculating the size and windings of this booster the following analytical discussion is necessary:

At normal load and normal battery voltage there should be neither charge nor discharge, and the booster voltage should be zero. Let the maximum voltage of battery equal  $2.3 N$ ,  $N$  being the number of cells in series. The normal voltage equal  $2N$ . The voltage due to the shunt coil should be *not less* than  $(2.3N - 2N) = .3N$ .

Let

$E_m$  = generator voltage at no load.

$E_a$  = battery voltage.

$V$  = booster e.m.f. due to shunt coil.

$I_0$  = generator current.

$I_x$  = current in external load.

$R$  = battery circuit resistance, including booster armature.

$t_1$  = number of turns in coil  $S_1$ .

$t_2$  = number of turns in coil  $S_2$ .

$K$  = volts produced per ampere turn on booster field.

$h$  = volts drop in generator voltage per ampere of generator current.

If  $I_0$  be first assumed as equal to the average generator current, then  $E_m - I_0 h$  = normal voltage at booster and battery terminals =  $E_0$ . If the generator is compounded to give a constant e.m.f.,  $h = 0$ . If it be overcompounded  $h$  is negative and  $E_0 = E_m + I_0 h$ .

In order that booster voltage shall be zero when  $I_x$  = average generator current,

$$I_0 (t_1 + t_2) K = V, \therefore t_1 + t_2 = \frac{V}{I_0 K} \dots \dots \dots (32)$$

As the load increases, the voltage due to the series coils must exceed  $V$  by an amount equal to the drop due to resistance of battery circuit, or

$$K (I_0 t_1 + I t_2) = V + R (I_x - I_0) \dots \dots \dots (33)$$

the current supplied by the battery being  $I_x - I_0$ . As  $I_0$  is to remain constant, the increase of series m.m.f. must be supplied by coil  $S_2$ . Then

$$K t_2 (I_x - I_0) = R (I_x - I_0), \text{ or } t_2 = \frac{R}{K} \dots \dots \dots (34)$$

From these equations, the windings of the three coils are determined. In using the factor  $K$  a constant permeability and straight line characteristic are assumed. This is sufficiently true for practical purposes. Remembering that the shunt coil voltage varies with variation in  $E_A$ , if connected across the battery terminals,  $V$  becomes

$$\frac{V E_A - V R I_x + V R I_0}{E_N} \dots \dots \dots (35)$$

in which  $E_N$  is the normal voltage of  $E_A$ .

With the shunt coil connected across the line, the equation of E.M.F.'s is

$$I_0 t_1 K + I_x t_2 K - V - E_0 + E_A + R I_0 - R I_x + I_0 h = 0. \quad (36)$$

But  $t_2 K = R$  (equation 34). Therefore,

$$I_0 = \frac{V + E_N - E_A}{t_1 K + R + h} \dots \dots \dots (37)$$

This shows  $I_0$  to be constant with a given value of  $E_A$  whatever the load variation.

If, however, the shunt coil be connected across the battery equation (36) becomes

$$I_0 t_1 K + I_x t_2 K - \frac{V E_A}{E_N} - \frac{V R I_x}{E_N} + \frac{V R I_0}{E_N} + I_0 h - E_0 + E_A + R I_0 - R I_x = 0 \dots \dots (38)$$

whence

$$I_0 = \frac{E_0 + \frac{V E_A}{E_N} - E_A + I_x \frac{V R}{E_N}}{t_1 K + R + \frac{V R}{E_N} + h} \dots \dots \dots (39)$$

With a given value of  $E_A$ , all the terms of this equation are constant, except  $I_x$  showing that  $I_0$  varies with  $I_x$ . The factor  $\frac{V R}{E_N}$  is, however, small. When battery voltage is normal,  $E_N = E_A$ , and

$$I_0 = \frac{V + I_x \frac{V R}{E_A}}{t_1 K + R + \frac{V R}{E_A} + h} \dots \dots \dots (40)$$

Consider now the concrete case of a railway circuit having the following characteristics:

$$E_M = 500 \text{ volts} = 2N.$$

$$N = \frac{500}{2} = 250 \text{ cells.}$$

$$E_A = 500 \text{ volts.}$$

$$V = .3N = 250 \times .3 = 75 \text{ volts, say, } 76.$$

$$I_0 = 100 \text{ amperes average.}$$

$$I_x = 400 \text{ amperes maximum.}$$

$$R = 0.2 \text{ ohm.}$$

$$K = .02 \text{ volts per ampere turn.}$$

$$h = 0 \therefore E_M = E_0.$$

Computations based on normal battery e.m.f.

$$t_1 + t_2 = \frac{76}{100 \times .02} = 38 \text{ turns.}$$

$$t_2 = \frac{.2}{.02} = 10 \text{ turns } \therefore t_1 = 28 \text{ turns.}$$

As, in practice, the battery is connected across the line,  $V$  is practically constant. Therefore, with  $E_A$  normal there will be no variation in  $I_0$ , whatever the load. If the line potential varies appreciably, equation (40) should be used, substituting line changes for battery changes.

$I_0$  maximum occurs when  $E_A$  is minimum.

$$I_0 = \frac{500 + 76 - 475}{.56 + .2} = 132.9 \text{ amperes. } I_0 \text{ is minimum when}$$

$E_A$  is a maximum.

$$I_0 = \frac{500 + 76 - 575}{.76} = 1.3 \text{ amperes.}$$

Therefore,  $t_1$  must be large enough to carry 133 amperes;  $t_2$  and armature must carry  $400 - 1.3$ , or practically 400 amperes. These extremes are only reached when the battery is used for carrying the peak of the load as well as compensating for fluctuations.

When used for regulation only, the battery voltage will vary but little, and the booster need not be so large as the foregoing figures would seem to require. Proper attention to the rheostat can prevent  $I_0$  from reaching the maximum value given, though the minimum value cannot be increased without increasing  $V$ , which would increase the size of the booster.

If the shunt coil be made to give a lower voltage on normal operation, than the figure assumed, by using a rheostat,  $t_1$  will be reduced; and while the regulation will be the same as that given when  $E_A$  is at its normal voltage, it will not be so good when  $E_A$  varies from normal. For good regulation with variation of  $E_A$ ,  $t_1$  must be large, which requires that  $V$  be large. Therefore, the full value of  $V$  or  $V_{max} = .3N$ , should be the normal working shunt voltage. Increasing  $V$  improves regulation, but increases the size of the booster, the size of machine required varying with the regulation necessary.

This type of booster is commonly installed with a switch to short circuit  $S_1$  and  $S_2$ , and allow the shunt coil only to act when a rapid battery charge is desired. The size of booster necessary in the case just considered would be  $400 \times 76 = 30.4$  kw considering shunt voltage only.

The series coils always oppose the shunt coils, and do not add materially to the capacity required of the machines, though the magnet limbs must be long enough to accommodate them. Since the maximum demand seldom comes and only lasts a few moments, 70 per cent. of the calculated capacity is large enough to make the machine in the present case equal 22 kilowatts.

If  $V = 76$  when  $E_A = 475$ —which would be the case if the



battery should discharge down to minimum and the rheostat receive no attention—the booster voltage on maximum external load  $= 76 - (28 \times .02 \times 133) - (400 \times 10 \times .02)$   
 $= 78.48$  volts and the amperes through the booster  
 $= \frac{475 + 78.5 - 500}{0.2} = 267$ . The product of these, or 19.9 kilo-

watts, is the maximum of the product of volts multiplied by amperes at any instant, and fixes the size of the motor re-

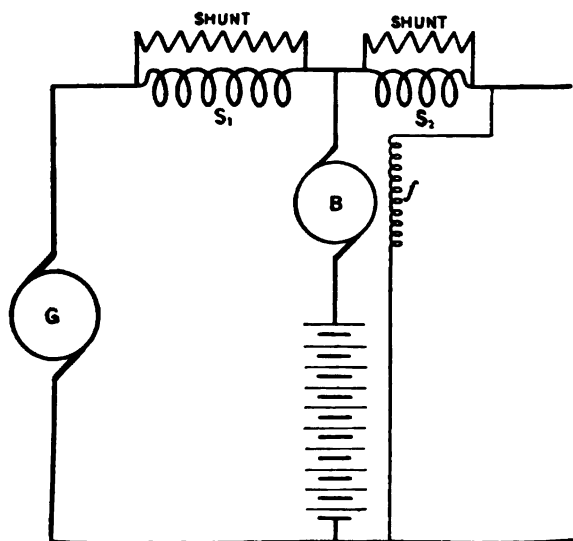


FIG. 125.

quired to drive if the booster is used only for regulation. Assuming 80 per cent. as booster efficiency the motor should be  $\frac{19.9 \times 1.34}{.80} = 33$  H. P.

Referring to coils S<sub>1</sub> and S<sub>2</sub>, it is evident that if given percentage of the generator and external currents respectively, be passed through them, the magnetization which they will produce will be proportional to these outputs just the same as if the total currents passed through these windings, and the booster will operate just the same if it were connected as shown in Fig. 125. As a matter of fact heavy shunts are

used across both these coils in practice and only a small portion of the currents pass through the windings. When shunts are used the number of turns in  $S_1$  and  $S_2$  are equal to the number calculated by equations (32) and (34) multiplied by the ratio of the total currents to the amount passing through the windings. Thus if the shunts across the coils carry nine-tenths of the total and one-tenth flows through the coils,  $t_1$  and  $t_2$  will be ten times the value computed by equations (32) and (34), while the cross section of the wire will be one-tenth as much as before. The volume of the coils and weight of copper remain practically the same in any case.

The series coil  $S_1$  is sometimes connected between the

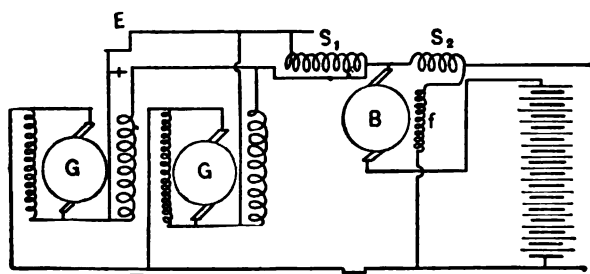


FIG. 126.

equalizer and positive bus bars when operated with compound generators, as shown in Fig. 126. In this case the current in the coil, while not in series with the generator current, gives an e.m.f. proportional thereto. To calculate the turns on  $S_1$  it is necessary to know the drop through the series coil of the generators, or what amounts to the same thing, the difference of potential between the positive and equalizer bus bars at normal load. The turns on  $S_1$  are then calculated as shunt coils producing a given armature E.M.F. with a definite voltage at its terminals.

This form of winding reduces the size of wire required to be wound on the field, though it does not reduce its volume nor the weight of copper, as compared with the regular series connection.

The sudden current rush from generator on increase of load is very much less in the differential than in the compound booster system, because of the self-induction of  $S_1$  and  $S_2$ , through which all current passes to reach the outside load provided no shunts are used and the connections are as shown in Fig. 124. If the booster be connected, as shown in Fig. 126, the reactance of  $S_2$  only, can assist in choking back the current rush.  $S_2$ , however, usually has a much smaller inductance than  $S_1$ , and the booster therefore will operate more satisfactorily on rapidly fluctuating loads when  $S_1$  is connected in series with the generator current.

Double commutators may be necessary on differential boosters under conditions of small  $V$  and  $I_x$  very great—generally on low potential systems.

## CHAPTER XXXIV.

### THE CONSTANT CURRENT BOOSTER.

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The regulating boosters before described—the compound and the differential—are adapted to systems where the lines are long and line drop is high, as they maintain the line voltage at normal at the point of their connection to the circuit, whatever the external load may be.

In systems where the lines are short and the drop small, it is often desirable to have the e.m.f. fall on application of overload. The reason of this is that the overload is produced by the current rush due to starting of motors, and if the e.m.f. be lowered the motors start more easily and the accelerating current is decreased.

This condition prevails in buildings where elevator, printing press and other motors are used, which frequently start and stop. For such systems the constant-current booster is best adapted, and it is now sometimes used on railway and other circuits of a like nature, being installed instead of the compound or differential. Of this type of booster there are only two kinds—one being the invention of J. B. Entz, and the other that of the author.

Patent No. 625,100, dated May 16, 1899, and issued to J. B. Entz, covers the system shown diagrammatically in Fig. 127.

In the diagram, G is the generator, B the booster armature, E battery, S series coil, *f* shunt coil, S<sub>1</sub> switch short-circuiting series coil, R rheostat, X, X, X, non-fluctuating load requiring constant potential, M M fluctuating load, and L L<sup>1</sup> the mains.

It is to be noted that all current used in the fluctuating load must pass through the series coil and armature, and that there is never a reversal of current in the booster; also that the voltage impressed on the fluctuating load is greater

than that on the non-fluctuating load by an amount equal to the booster voltage.

The shunt coil creates an e.m.f. in the same direction as the generator E.M.F. The series coil opposes the shunt and generator E.M.F.'s.

Should a load come on the power circuit, the generator tends to send additional current through the booster to meet this demand. The action of increased current is, however, to cut down the e.m.f. of the booster in a direct proportion, causing the generator with the booster to give an e.m.f. that

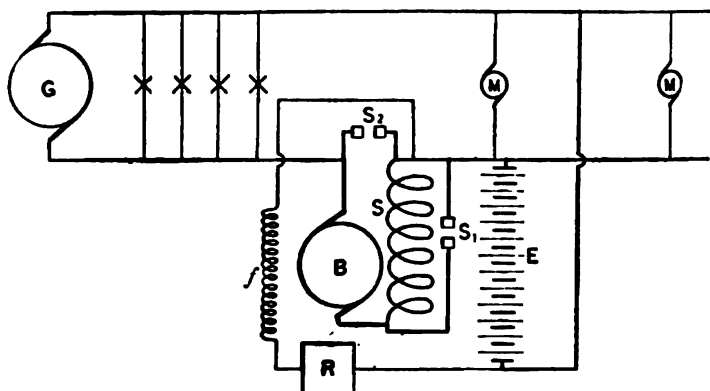


FIG. 127.

varies inversely as the resistance of the power circuit, thus causing under any condition—up to full battery charge—a constant-current delivery from the generator.

On systems where the battery serves for regulation only and the charges and discharges are not widely different in amount, the booster carries only the *average* current and not the maximum of the fluctuations, as is the case with the series, compound and differential systems. The machine and its driving motor may therefore be considerably smaller than would be required if those types were used.

Following is an analytical discussion of the constant-current booster:

Let

$E_g$  = generator voltage at on load.

- $E_o$  = normal line voltage on generator side of booster.  
 $E_A$  = normal battery voltage.  
 $E_x$  = battery voltage at any condition of charge.  
 $E_b$  = booster voltage.  
 $V$  = voltage due to shunt coil at normal battery voltage.  
 $t$  = number of turns in series field.  
 $I_o$  = generator current to power.  
 $I_x$  = current in external load.  
 $R$  = resistance of battery circuit.\*  
 $r$  = resistance of booster armature and series field.  
 $K$  = volts produced per ampere turn on booster field.  
 $N$  = number of cells in series.  
 $h$  = volts drop at generator per ampere of generator current.

The minimum battery voltage should be the same as the generator voltage, as it is often desirable to connect the battery on to the generator circuit by closing  $S_2$ , and supply the lighting current for short periods during which the generator is shut down and disconnected from the circuit.

$$\text{Therefore, } N = \frac{E_o}{1.8}$$

The battery is installed with some of the cells on one end connected to points on an end-cell switch, and so arranged that when connected on the lighting load and discharging only, these cells can be cut in as the voltage drops. This arrangement will be explained later.

The maximum charging voltage of battery, and consequently the maximum voltage across the power bus bars, is  $2.5 N$ . The average voltage will be  $2 \times N$ . The voltage due to the shunt coil will for purposes of calculation, be assumed, as equal to the difference between the generator voltage and the maximum battery voltage, or  $2.5 N - E_o$ .

When the outside load is normal and the battery is at normal voltage, the booster E.M.F. =  $E_A - E_o + r I_o \dots (41)$

---

\*Virtual Resistance.

and current flows neither into nor out of the battery. Therefore,

$$V - t I_0 K = E_A - E_0 + r I_0 \dots \dots \dots (42)$$

whence

$$t = \frac{V - E_A + E_0 - r I_0}{I_0 K} \dots \dots \dots (43)$$

This assumes a constant permeability. Knowing  $V$ ,  $E_A$ ,  $E_0$ ,  $K$ ,  $r$  and also the average load or  $I_0$ ,  $t$  is determined. Remembering that the voltage of the shunt coil will vary directly as the voltage of the battery to which it is connected its e.m.f. for any battery voltage will be

$$\frac{V E_x - V R I_x + V R I_0}{E_A}$$

For any external load or battery voltage, the following is the equation of e.m.f.'s:

$$\frac{V E_x - V R I_x + V R I_0}{E_A}$$

$$- I_0 t K - I_0 r - I_0 h + E_0 - E_x = R (I_0 - I_x) \dots \dots (44)$$

whence

$$I_0 = \frac{E_0 + \frac{V E_x}{E_A} - E_x + I_x \left( R - \frac{V R}{E_A} \right)}{t K + r + R - \frac{V R}{E_A} + h} \dots \dots (45)$$

Since for any given condition of battery, all the factors in equation (45) are constant, except  $I_x$ , the generator load varies with the external load. It is evident that the higher  $V$  is made the better the regulation will be.

If the shunt coil be connected across the bus bars on the generator side,  $V$  will be a constant and equation (44) will become

$$V - I_0 h - I_0 t K - I_0 r + E_0 - E_x = R I_0 - R I_x \dots (46)$$

and

$$I_0 = \frac{E_0 + V - E_x + I_x R}{t K + r + R + h} \dots \dots \dots (47)$$

This shows that the regulation is better with the shunt coil connected across the battery terminals.

The following example will illustrate the methods of calculation:

Assume a 125-volt, two-wire system furnishing current to lights and electric elevators. Assume

$$I_0 \text{ average} = 50 \text{ amperes.}$$

$$I_x \text{ maximum} = 300 \text{ amperes.}$$

$$r = .2 \text{ ohm.}$$

$$R = .2 \text{ ohm.}$$

$$K = .02.$$

$$E_0 = 125 \text{ volts.}$$

$$h = 0.$$

$$N = \frac{125}{1.8} = 69.6, \text{ say } 70.$$

$$E_A = N \times 2 = 140 \text{ volts} = \text{average voltage across power mains.}$$

$$E_{A \text{ max}} = 2.5 \times 70 = 175 \text{ volts.}$$

$$E_{A \text{ min}} = 70 \times 1.8 = 126 \text{ volts.}$$

Range of voltage through which motors operate = 49 volts.

Assume  $V = 100$  volts.

$$\text{Then } t = \frac{100 + 125 - 140 - .2 + 50}{50 \times .02} = 75 \text{ turns.}$$

Assume  $I_x = 0$ . Then

$$I_0 = \frac{100 + 125 - 140}{75 \times .02 + .2 + .2 - \frac{100 \times .2}{140}} = 48.4 \text{ amperes.}$$

If  $I_x = 50$  amperes,

$$I_0 = \frac{85 + 50 \left( .2 - \frac{.2 \times 100}{140} \right)}{1.756} = 50 \text{ amperes; and for } I_x$$

$$= 300, I_0 = 57.8 \text{ amperes.}$$

The minimum generator current will be when the battery is at its maximum voltage, and  $I_x = 0$ .

$$\text{Then } I_0 = \frac{100 + 125 - 175}{1.756} = 28.5 \text{ amperes.}$$



$I_0$  is a maximum when  $E_A$  is a minimum, and  $I_x = 300$ . Then

$$I_0 = \frac{100 + 125 - 126 + 300 (.0572)}{1.756} = 65.8 \text{ amperes.}$$

Proper attention to the rheostat should prevent  $I_0$  from ever rising so high.

If  $V$  were 50 volts,  $I_0$  would be 42.2 amperes for  $I_x = 0$ , and 88.5 amperes for  $I_x = 300$  amperes with  $E_A$  normal. With  $E_A = 126$  volts and  $I_x = 300$ ,  $I_0 = 105.4$  amperes.

$V$  then is determined by the regulation desired. The higher  $V$  is the better the regulation, but the size of the machine increases with increase of  $V$ .

While the generator current varies with any variation of

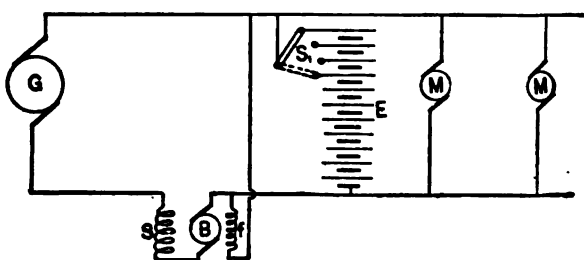


FIG. 128.

$E_A$ , the latter changes gradually, and does not cause any sudden fluctuation. If the battery is used only for regulation, its e.m.f. will vary but little; but if used to carry light loads or help the generator carry the peak of the load,  $E_A$  will vary from 2.5 N down to 1.8 N, and rheostatic control is desirable.

The size of the booster required in the example just given is maximum shunt voltage  $\times$  armature capacity. If  $V$  be sufficiently high to send 10 per cent. of the average current into the battery when  $E_A$  is maximum, it is great enough for all charging purposes.  $V$  maximum, therefore, never exceeds  $V$ . In the case under consideration,  $I_0 \text{ max} = 68.5$  amperes, and  $V = 100$  volts. The booster is therefore a 6.85-k.w. machine; 70 per cent. of this, or 5 kilowatts, will be large enough to make this booster.

The size of motor required is fixed by the product of booster volts multiplied by amperes taken at the same instant and when their product is a maximum.

This maximum occurs when the series field is short circuited by closing  $S_1$  (see Fig. 127), and a charging current is being sent into the battery, and  $E_A$  is maximum. If this current = 50 amperes,  $E_A = 175$ ; booster voltage =  $E_A - E_o = 50$ .

Therefore, the size of the motor is  $\frac{2.5}{.80} = 3.1$  K.W., .80 being assumed as the booster efficiency at full load.

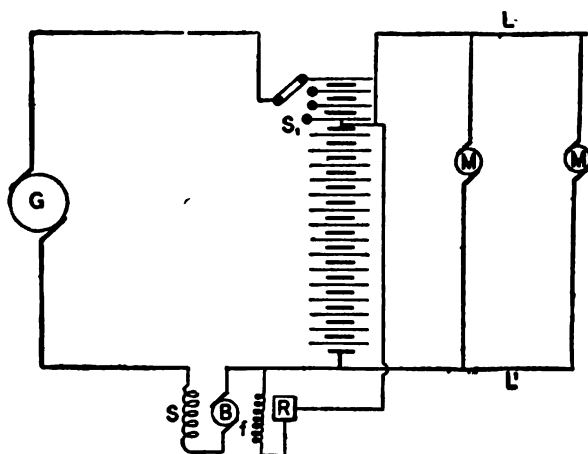


FIG. 129.

The end-cell arrangement before mentioned may be as indicated in Fig. 128 or Fig. 129. In Fig. 128 the circuit is from L through all the cells out to L, when the end-cell switch  $S_1$  is thrown on the last point, as shown by the full line. When the generator is cut out and the battery used as the source of supply, the end-cell switch is thrown on such a point as will place in series between the mains the proper number of cells to give the normal voltage of the generator side of the system.

With this arrangement it is evident that the voltage fluctuation on the power side of the system equals 1.8 N to 2.5 N. A better arrangement is shown in Fig. 129. In this, the

battery, exclusive of end cells, is connected across the power line. The end cells connect to the generator line through the end-cell switch, S.

The voltage of the power bus bars in this case is lower than with the connections shown in Fig. 128, and is not so much in excess of the voltages of the generator side of the system. The maximum fluctuation is less because there are fewer cells in series on the power bus.

Another type of constant-current booster was patented by the author under No. 648,874, on May 1, 1900, and assigned to the National Battery Company. This differs from the

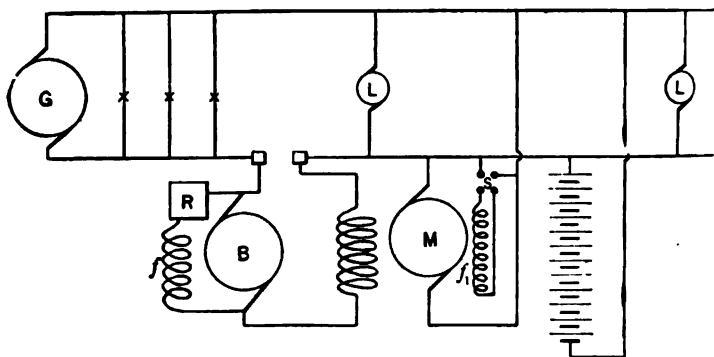


FIG. 130.

other boosters described in that it varies its e.m.f. by speed changes. It is shown diagrammatically in Fig. 130.

G is the generator, B the booster, and M the driving motor. The booster is a shunt machine as indicated. The motor is a shunt motor with its armature connected across the battery and its fields connected to the generator bus bars.

The current passes from the generator through the booster, where the e.m.f. is raised, and through a series coil on the driving motor to the power line. The battery is connected across the power line as shown. The magnetization of the series coil on the motor assists that of the shunt coil. The operation of this system is as follows:

Under normal conditions of load and battery voltage, the generator e.m.f. plus booster e.m.f. is just sufficient to send

normal current into the external load, and the battery neither discharges nor receives current. The booster e.m.f. is dependent on the speed of rotation of the armature B, and this speed varies with the magnetization of motor, M.

If an increased load come on the system there will be a tendency towards increased flow through the booster. The voltage of the booster will fall, due to increase of armature reaction and decrease of motor and booster armature speed. The fall in speed is produced both by the increased counter torque of the booster and the increase of motor field strength.

The booster and motor are both designed to work at a low magnetic density so that they may be susceptible to changes in the applied M.M.F.

In practice, the shunt coil is used only when the motor is starting. When it comes up to speed and the load comes on the booster, the motor shunt coil is cut out and the field is produced entirely by the series coil. Since the current through the booster and the series coil is approximately constant, the motor is practically the same as a shunt motor in its operation.

The several changes that occur are inter-dependent, and though the system itself is simple, the mathematics are somewhat complicated, and cannot be put in convenient general form for the reason that the characteristic of the booster must be taken into account. The best method of explaining the calculation of this booster is by a concrete example.

Assume a plant in which the E.M.F. of generator is 110 volts.

Current (average) to the power circuit 50 amperes.

Minimum current taken from power  
circuit ..... = 0

Maximum current taken from power  
circuit ..... 250

Booster voltage at normal load ..... 20 volts.

The voltage across the power bus bars is  $110 + 20 = 130$  volts normal.

The number of cells across the power bus bars  $= \frac{130}{2.05} = 63.$

Voltage across power bus bars when battery is discharging on maximum load  $= 1.88 \times 63 = 118$  volts, and the booster voltage  $= 8$  volts.

When the load on the power circuit is zero and the normal current is being charged into the battery the voltage  $= 2.15 \times 63 = 135$  volts and booster voltage  $= 25$ .

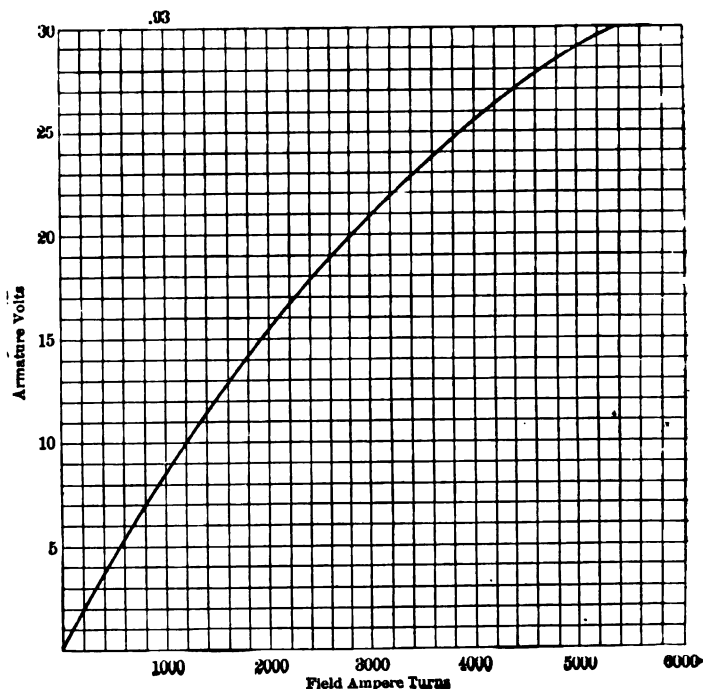


FIG. 131.

The normal voltage across the motor shunt field is 110 volts, while that across the motor armature is 130 volts.

The maximum booster voltage is  $= 63 \times 2.6 - 110 = 47$  volts, and the current carrying capacity should be about 25 per cent. above the normal current being in this case 62.5 amperes. The machine is therefore a 2.93, say 3 K W generator. The speed of the booster adopted will be 1000 r.p.m. normal. Take the characteristic of the type of dynamo of this size. This is shown in Fig. 131.

From the characteristic, the normal point at which the booster will work is found to be where the horizontal line at the height corresponding to 20 volts cuts the curve. The required ampere turns on the booster field are seen to be 2860.

The magnetizing current may be made as small as desired by winding on sufficient copper. In good practice, 2 per cent. of the current output is usual.

$.02 \times 62.5 = 1.35$  amperes at the field at normal load.

$$\frac{2860}{1.35} = 2120 \text{ shunt turns on the booster.}$$

The motor is wound with a sufficient number of shunt turns to start and run at about 1000 r.p.m. It will be about the same type of machine as the generator. Assume the number of ampere turns necessary to give the required speed of 1000 r.p.m. to be 3000. Then, since the total field is furnished by the series windings after starting up, the number of series turns  $= \frac{3000}{50} = 60$ . Allowing 5 amperes as the shunt field current for starting, the number of turns  $= \frac{3000}{5} = 600$ .

When the maximum current demand occurs, the booster E.M.F. must fall to 8 volts. At 8 volts the ampere turns on the booster field  $\frac{2860 \times 8}{20} = 1144$ . This corresponds on the characteristic to 9.5 volts at 1000 r.p.m. The speed must therefore decrease in the ratio of 8 to 9.5, or 15.8 per cent. This will be  $1000 - 158 = 842$  r.p.m. The voltage across the motor armature has decreased from 130 to 118, which will bring the speed down to  $\frac{1000 \times 118}{130} = 908$  r.p.m.

A slight increase of current through the booster and the motor field will bring the speed down to the required value. The motor field must change in the ratio of 908 to 842 or 7.3 per cent. The current from the generator, then, on maximum power load is  $50 + .073 \times 50 = 53.7$  amperes.

When the load on the power circuit is zero and approxi-

mately normal, current is being charged into the battery, the booster E.M.F. is 25 volts and field ampere turns =  $\frac{25 \times 2860}{20} = 3575$ , corresponding on the characteristic to 23.5 volts at 1000 r.p.m. The speed must therefore increase in the ratio of 23.5 to 25, or 6.4 per cent., making the required speed 1064. The increase in motor speed due to change in voltage across the power bus bars is  $\frac{1000 \times 135}{130} = 1040$ . The current through the booster and the motor fields must decrease in the ratio of 1040 to 1062, or 2.12 per cent. The minimum current, therefore, will be 50 - 2.12 per cent. = 48.9 amperes.

The total load change on the generator, therefore, is from 49 to 53.7 amperes for variations of from zero to 250 amperes on the power circuit

## CHAPTER XXXV.

### SEPARATELY EXCITED BOOSTERS.

Patent No. 651,664, granted A. S. Hubbard, on June 12, 1900, describes a separately excited booster system which is as shown in Fig. 132. G is the supply generator, E a battery, B the booster armature connected in series with the battery, the two being connected across the mains, L and

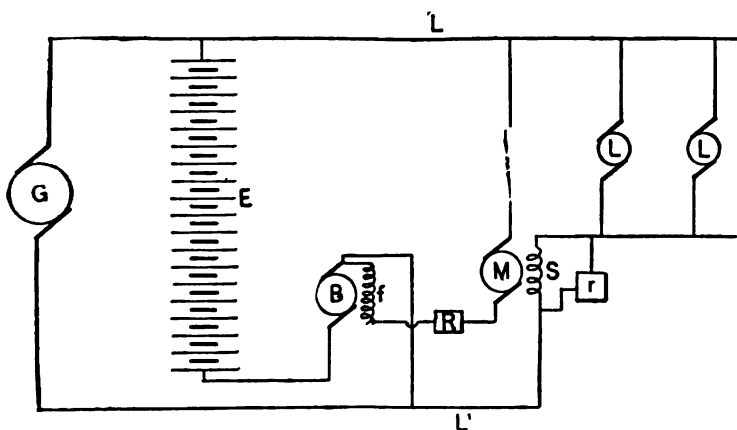


FIG. 132.

L'. M is the armature of a counter e.m.f. generator connected in series with the field, *f*, of the booster, the two being also connected across the mains L L'. A rheostat R is included in the circuit.

S is the field of the counter e.m.f. generator, and carries a current proportional to the total external load, the proportion being regulated by means of the adjustable shunt, *r*, which is in parallel with S. The operation of this system is as follows:



The e.m.f. of the booster is in opposition to, or in the same direction as, that of the operator, according to whether the e.m.f. of *M* is greater or less than that of the line. The e.m.f. of the counter e.m.f. generator opposes the current flow through shunt field *f* of booster. The e.m.f. of counter e.m.f. generator varies with the external load, thus causing the booster e.m.f. to vary with the external load.

At normal load the battery and generator e.m.f.'s balance and there is no battery charge or discharge. The voltage of *M* being equal and opposite to the line voltage, no current flows either way through *f* and the booster gives no e.m.f. in either direction.

If the load should increase, the voltage of *M* will exceed that of the line, and current will flow through *f* in such a direction as to cause discharge. A decrease of load will result in a lower e.m.f. at *M* and the line voltage being greater will pass current through *f* in such a direction as to cause charge, the booster e.m.f. being added to the generator e.m.f.

It may also be connected so that the booster e.m.f. is to assist the generator and the battery, e.m.f. being equal to generator e.m.f. plus booster e.m.f. at normal load. In this case the line voltage is always greater than that of *M*, and current passes through *M* and *f* from the line. With a heavy load through *S*, the voltage of *M* is increased, reducing the flow from the line through *f*, and thereby decreasing the booster voltage. This allows the battery to discharge and assist the generator. Conversely, a light load reduces the e.m.f. of *M* opposing the line voltage and the voltage of the booster is increased, resulting in battery charge. In practice, however, it is connected as first described, to give zero voltage at normal load.

On discharge, the battery output is proportional to the excess of load up to the limit of saturation of the field magnets of *M* and this system was designed with a view to limiting the discharge of the battery, and in case of the load exceeding the normal generator plus maximum battery output, to stop the booster voltage from rising proportional to the load, and so make the generator work at an overload

rate, and assist the battery, thus in a measure protecting it from ruinous discharge rates.

This system is known in the trade as the Counter E.M.F. System.

The mathematical discussion of the system is as follows:

Let

$E_A$  = voltage of battery on open circuit.

$E_b$  = voltage of booster at any time.

$E_0$  = voltage of generator at no load.

$h$  = drop in generator voltage per ampere output.

$I_0$  = amperes generator output.

$I_x$  = amperes taken by external load.

$R$  = virtual resistance of battery and booster circuit.

$K$  = volts generated in exciter armature per ampere turn on its field.

$Q$  = volts generated by booster armature per volt of impressed e.m.f. across its fields.

$T$  = number of turns on exciter field.

Since battery charge or discharge is effected by the change in booster e.m.f. and is proportional to excess or deficiency of  $I_x$  above  $I_0$  the change in booster e.m.f. due to change in  $I_x$  must be equivalent to (the resulting current through the battery) multiplied by (the virtual internal battery resistance plus the booster and circuit resistance) that is:

$$QTKI_x = RI_x \dots \dots \dots (48)$$

or  $R = QTK$ , whence,

$$T = \frac{R}{QK} \dots \dots \dots (49)$$

series turns on exciter field.

$Q$  and  $K$  are determined by the design of the machines,  $Q$  being fixed by the condition that when no current is flowing in the line ( $I_x = 0$ ) the voltage across the booster field is equal to the line voltage, and the booster armature voltage must be equal to the amount required to send the average current into the battery. That is for  $I_x = 0$ .

$$E_b = E_A + RI_0 - E_0 \dots \dots \dots (50)$$

$$QE = R + RI_0 - E_0 \therefore Q = \frac{E_A + RI_0 - E_0}{E_0} \dots \dots \dots (51)$$

The general equation of Electromotive forces is:

$$E_o - I_o h = E_A - R(I_x - I_o) + E_b \dots \dots \dots (52)$$

The sign of  $E_b$  being negative for charge and positive for discharge.  $(I_x - I_o)$  = battery current which is discharge when the algebraic sum is positive and charge when negative.

$$E_b = (E_o - I_o h - I_x TK) Q \dots \dots \dots (53)$$

the quantity in the parenthesis representing the net voltage available to force current through  $f$ .

Substituting in equation (52) the value of  $E_b$  in (53)

$$E_o - I_o h = E_A - R(I_x - I_o) + Q(E_o - I_o h - I_x TK) \dots \dots (54)$$

whence

$$I_o = \frac{E_o(1+Q) - E_A + I_x(R - TKQ)}{h(1+Q) + R} \dots \dots \dots (55)$$

for  $E_b$  negative. Since, however,  $R = TKQ$ , the equation is finally

$$I_o = \frac{E_o(1+Q) - E_A}{R + h(1+Q)} \dots \dots \dots (56)$$

For a constant potential generator  $h = 0$  and the equation becomes

$$I_o = \frac{E_o(1+Q) - E_A}{R} \dots \dots \dots (57)$$

These equations show that if the characteristics of both exciter and booster are straight lines,  $I_o$  is constant and independent of  $I_x$ , for a given state of battery charge. If the booster opposes the discharge from battery and the exciter voltage is always less than that of the line, the two combined characteristics will be practically a straight line, since with increase of magnetization of  $M$  there is a decrease for  $B$  and the variations of permeability will approximately balance.

It is evident that this system would be operative if the exciter  $E$  fed directly to the field  $f$ , and it is sometimes so

installed, a differential field connected across the battery being also around the exciter armature.

A concrete example of calculation of this system is as follows:

Assume

$$E_o = 110 \text{ volts.}$$

$$E_A = 110 \text{ volts.}$$

$$I_o = 330 \text{ amperes.}$$

$$I_{x \max} = 730 \text{ amperes.}$$

$$R = .03 \text{ ohms.}$$

$$K = .015$$

$$N = \text{No. of cells in series} = \frac{110}{2.05} = 54 \text{ cells.}$$

Then

$$Q = \frac{110 - 110 + (330 \times .03)}{110} = .09$$

$$T = \frac{.03}{.015 \times .09} = 22.2 \text{ say } 22 \text{ turns.}$$

The booster must be capable of giving a voltage high enough to overcharge the batteries when there is no outside load. This is equal to  $54 \times 2.6 - 110 = 31$  volts. The machine should be wound to give a voltage slightly higher, say 35 volts.

Call Z, the volts generated in the booster armature per ampere turn on the field, and assume it equal to .02 for the type of machine under consideration. Then the number of ampere turns required on the field when ending charge

$$= \frac{35}{.02} = 1750.$$

The volts across the booster field will be equal to the line voltage = 110 since there is no current in the exciter field. Assume the number of turns = 1200, then amperes on full excitation = 1.46. The resistance of the field =  $\frac{110}{1.46} = 75.4$  ohms.

When working on regulation the voltage must be reduced by the rheostat R in series with the field. It is desired that approximately full generator current shall flow into the

battery when there is no external load. This requires a booster voltage =  $110 + (330 \times .03) - 110 = 9.9$  volts.

$$\frac{9.9}{.02} = 495 \text{ ampere turns.}$$

$$\frac{495}{1200} = .4125 \text{ amperes in booster field.}$$

With  $I_x = 0$ , the exciter counter e.m.f. = 0, and voltage across the booster field = 110 = line voltage.

$$\frac{110}{.4125} = 267 \text{ ohms, which is the resistance necessary to}$$

keep the field current at its proper value.  $267 - 75.4 = 191.6$  ohms required in the rheostat.

The capacity of the booster is 35 volts and  $730 - 330$  amperes = 14 K. W. Since the maximum load is a rapidly fluctuating one, 70 per cent. of this capacity or 9.8 or say 10 K. W. is ample.

The maximum current through the counter e.m.f. exciter is when the rheostat is cut out, and there is no load in external circuit = 1.46 amperes. Its maximum voltage must be sufficient to cause full battery discharge when  $I_x = 730$  amperes, and rheostat resistance of 191.6 ohms is in circuit.

The booster voltage assisting to discharge must be  $400 \times .03 = 12$  volts when  $I_x = 730$  amperes. Ampere turns required on booster field =  $\frac{12}{.02} = 600$ . Since there are 1200 turns, the field current = .5 ampere. The resistance of the field circuit and rheostat is 267 ohms requiring 133.5 volts to send .5 ampere through the field which is the excess above the line voltage necessary.

Exciter voltage maximum =  $133.5 + 110 = 243.5$  volts.

When  $I_x$  is maximum = 730 amperes the exciter voltage =  $730 \times .015 \times 22.2 = 243$  volts. The magnetization to produce this voltage should be well up on the curve, so that further increase of  $I_x$  would result in an increase of  $I_o$ , the exciter voltage failing to rise proportionally to the increase in  $I_x$ , and causing the generator to supply the current for further overload.

The maximum exciter armature current is 1.46 amperes.  
 $243 \times 1.46 = 355$  watts = size of counter e.m.f. generator.

The total external current does not pass through the field of the counter e.m.f. generator, but only a small portion, most of it passing through the adjustable shunt  $r$ . The turns on the C.E.M.F. machine are increased in proportion to the amount shunted, and the cross section of the wire or ribbon with which the fields are wound, is reduced by a like factor.

The product of volts by amperes is a maximum when the battery is being discharged at the one hour rate, and is equal to  $12 \times 400 = 4.8$  K. W. The counter e.m.f. machine is at this time working at its maximum rate of 355 watts. Allowing 80 per cent. booster and 70 per cent. exciter efficiencies the H. P. of the driving motor is

$$\left( \frac{.355}{70} + \frac{4.8}{80} \right) \times 1.34 = 8.8 \text{ H. P.}$$

The load being fluctuating 80 per cent. of this computed capacity will be sufficient = 7.04 say 7 H. P.

In practice, the three machines are all mounted on the same shaft and bed plate.

The booster, devised by J. S. Highfield, of England, belongs also to the separately excited class, and differs from the other boosters before described in that it depends for its operation on the change in voltage at the battery terminals with change in load. It therefore is not suitable to use on regulation with compounded generators unless it be placed far enough away from the power station for the line drop to exceed the voltage rise of the generator, giving as a net result a decrease in voltage with increase in load, or the series generator fields so arranged with one or two cells in circuit as before described, so that a drop always attends a load increase. It, however, is well adapted to work on continuous battery discharge, as a voltage regulator taking the place of end cells.

Fig. 133 shows, diagrammatically, the connections of this system. G is the generator, E a small direct current shunt

wound generator, the armature of which is connected to the terminals of the battery passing through  $f$ , which is the main field of the booster dynamo,  $B$ .  $S$  is a series field in parallel with the variable shunt  $R$ . The voltage of the exciter  $E$  is equal to the battery E.M.F. under normal condition of load, that is, when the external load is equal to the normal generator output.

If the load should diminish, the generator voltage will rise tending to send current into the battery. This causes the potential at the battery terminals to exceed that of  $E$  and a current from the battery will therefore flow through  $f$  and  $E$

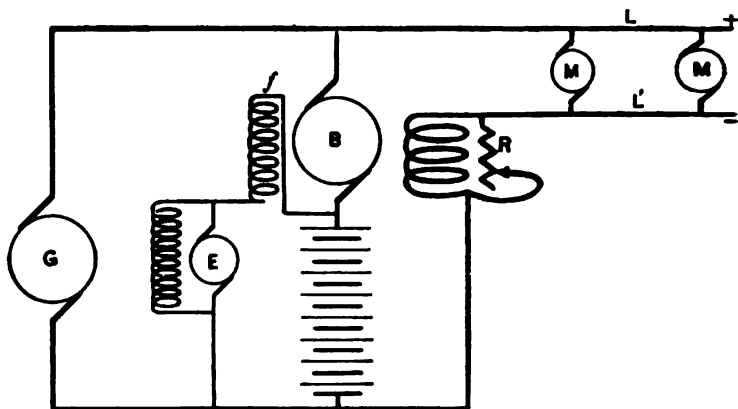


FIG. 133.

in a direction opposite to the E.M.F. of  $E$ . The winding  $f$  of  $B$  is in such a direction that current flowing against the E.M.F. of  $E$  increases the booster E.M.F., and it assists the generator to charge and at such a rate as if determined by the difference between the battery and exciter E.M.F.'s.

Conversely, an increase of load, lowering the generator E.M.F. causes the battery to begin discharge, and as the voltage at the battery terminals falls,  $E$  sends current through  $f$  to the battery, and the E.M.F. of  $B$  is in a direction to assist discharge.

The series field  $S$  is to compound the combined battery and generator currents, it increasing the voltage of  $B$  on discharge of heavy currents. The two auxiliary machines may

be driven in any convenient way, but usually a shunt wound electric motor is used, the three frames being mounted on one base plate, and the three armatures on one continuous shaft. The booster fields are laminated and worked well below the knee of the magnetization curve, giving a characteristic which is nearly a straight line. In operation there are times when a heavy current may be passing through the armature, and the field is weak and the armature reaction then becomes comparatively excessive. A few series turns are usually wound on the fields to annul the armature reaction. These are not shown in the figure.

The analysis of this system is very simple. The E.M.F. of  $B$  is always equal to the drop in the battery on discharge or increase in battery voltage on charge. That is

$$E_b = R(I_x - I_o) \dots \dots \dots (53)$$

in which  $E_b$  = booster voltage,  $R$  = virtual internal resistance of battery, plus ohmic resistance of connections and booster armature;  $I_x$  and  $I_o$  = external and generator currents respectively, and their algebraic difference the current through the battery being discharged when the quantity is positive and charge when negative.

Call

$E_o$  generator voltage at no load.

$E_n$  battery voltage at no load.

$h$  = drop in generator voltage per ampere.

$k$  = volts induced in booster armature per ampere turn on the field.

Then

$$E_o - I_o h = E_n - R(I_x - I_o) - E \dots \dots \dots (59)$$

but since  $E_b = R(I_x - I_o)$  the equation becomes  $E_o - I_o h = E_n$  whence

$$I_o = \frac{E_o - E_n}{h} \dots \dots \dots (60)$$

This shows that  $I_o$  varies only when  $E_n$  changes, and is greater when  $E_n$  is minimum.

The effective E.M.F., sending current through  $f$  is the



difference between the battery voltage on open circuit and that of charge or discharge. Therefore the voltage across  $f$  is at any time equal to the change in battery voltage or which is the same as the booster voltage. Hence the booster armature must induce one volt for each volt potential at the terminals of  $f$ .

$f$  may be wound with as many turns as is convenient, the size of the wire being such that the resistance per mean turn is equal to  $k$ . This is derived as follows:

$\frac{1}{k} = SI =$  ampere turns on field per volt induced in armature, in which  $S$  = number of turns on field and  $I$  = field current.

$$\frac{SI}{S} = \text{amperes in field per volt induced in armature.}$$

$$\text{Resistance of field } R_f = \frac{1}{I}$$

$$\text{Resistance of a single turn} = \frac{1}{SI} = k.$$

The greater the number of turns and consequently the higher the resistance of the winding, the smaller will be the exciter.

Assume a system in which:

$$E_o = 125 \text{ volts.}$$

$$E_n = 110 \text{ volts.}$$

$$h = .03.$$

$$k = .02.$$

$$I_o = 500 \text{ amperes.}$$

$$I_x \text{ max} = 2000 \text{ amperes.}$$

$$R = .01 \text{ ohm.}$$

The maximum battery output is  $2000 - 500 = 1500$  amperes.

$$I_o h = 500 \times .03 = 15 \text{ volts.}$$

$$E_o - I_o h = 110 \text{ volts} = E_n.$$

Since the booster voltage must always be equal to  $R(I_x - I_o)$  and also equal to the E.M.F. impressed on its field, it may be taken as equal to the change in battery voltage from  $E_n$  for any given charge or discharge. Thus when  $I_x = 0$ , and it is desired that  $I_o$  shall remain constant, the

voltage at the battery is increased  $.01 \times 500 = 5$  volts = booster voltage in direction of charge, *i. e.*, the battery voltage exceeds that of the line by 5 volts when charged at the rate of 500 amperes, assuming that the cells are far below the point of gassing. Conversely when there is a discharge of 500 volts, the battery voltage is 5 volts less than that of the line and this must be the booster E.M.F. in a discharging direction.

The maximum booster voltage—that of overcharge— $= (55 \times 2.6) - (125 - 200 \times .03) = 24$  volts, say 25, 200 amperes being assumed as the maximum current through battery on overcharge.

Maximum current through booster armature = 1500. Booster capacity  $= 25 \times 1500 = 37.5$  K. W. If maximum amperes are momentary only, this capacity may be reduced.

The motor to drive has its capacity fixed by the maximum output of 1500 amperes when the battery is at its lowest stage, *i. e.*, 1.8 volts per cell. Booster voltage  $= 110 - 55 \times 1.8 = 11$  volts. Then motor capacity

$$= \frac{11 \times 1500 \times 1.34}{80\%} = 27.6 \text{ H. P.}$$

The factor .80 is the as-

sumed efficiency of the booster. If the size of booster is reduced below the maximum requirement—as it should be in practice—the power of the motor should be reduced in like proportion.

The size of exciter is determined by the resistance of the booster field and the normal voltage of the battery. Assuming the resistance of the booster field is 4 ohms, the current through exciter armature at maximum booster voltage is  $\frac{24}{4} = 6$  amperes. The size of the exciter then is

$6 \times 110 = 660$  volts. If there were twice as many turns on the booster field, its resistance would be doubled and the exciter capacity would be only 330 watts.

A third type of separately excited booster is that of Norman W. Storer\* shown diagrammatically in Fig. 134.

G is a generator, B<sub>1</sub> a booster, E an exciter having series

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\*Patent No. 695,962.

fields,  $S_1$  and  $S_2$ , and a shunt field  $f$  which is connected across the line, and is in opposition to  $S_1$  and  $S_2$ .

$T$  is the booster field excited from  $E$ . As may be seen, the exciter field  $S_1$  is in series with the generator, and  $S_2$  is in series with the line—the whole arrangement of the exciter fields being identical with that of Entz's differential system. Instead of the armature  $E$  carrying the battery current, however, it excites the field  $T$  and armature  $B$ . The analysis

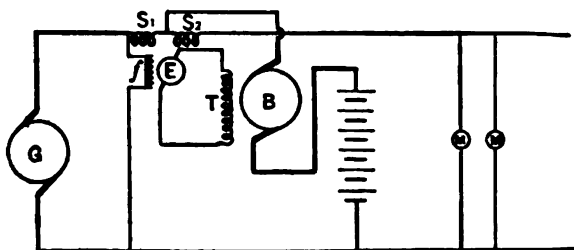


FIG. 134.

effect and operation are all identical with the system referred to, except that a factor  $\phi$  must be included, which represents the volts produced in armature  $B$ , per volt applied at its field terminals.

In all booster systems which are separately excited, the exciter is generally mounted on the shaft with the driving motor and booster, and these being many times larger than the exciter, the speed of the latter is very slow for so small a machine. Therefore a larger frame is required for the exciter than for a machine of the same output running at its proper speed.

## CHAPTER XXXVI.

### NOTES ON DESIGN AND SELECTION OF BOOSTERS.

---

In designing automatic boosters the frames must always be large enough to work below the knee of the magnetization curve, if exact regulation is desired. This same rule applies to the design of driving motors where they are to work on lines fed by shunt dynamos. Otherwise the regulation of the boosters will not be good, and the motors will "hunt" when the load changes, owing to change of line potential. A weak motor field allows sufficient change, in magnetization with change of applied E.M.F. to compensate for its effect on the armature. In the foregoing discussions straight characteristics have been assumed, and on this premise the equations and results have been deduced. As a matter of fact, however, no characteristic is straight and the theoretical regulation can never be attained.  $I_o$  will always vary slightly with external load. This variation is least with separately excited boosters, in which one machine is nearest saturation, while the other is zero and vice versa, the curves neutralizing and producing a practically straight characteristic as a resultant:

The variation is greatest in separately excited booster systems, in which the exciter and the booster both rise in magnetization together. In this case, the bend of the characteristic becomes cumulative and departs more from a straight line than does that of either machine separately. However, all the systems herein described, work well within the limits of good regulation.

In determining the field turns, select the point on the characteristic about which the booster will most generally work, and consider this as the point on a straight characteristic. In reversible boosters in series with the battery, the

fields of which pass through zero, this point should be taken as about half-way from the zero along the curve.

In the case of constant current boosters, which are not in series with the battery, this point is located by considerations of load change, and average rate of working.

This of course refers to methods to be used when exact regulation is desired. Usually, however, on load curves, peaks occur at infrequent intervals which exceed the one hour rate of the battery, plus the normal generator current in which case it is much better to overload the generator for a short while, than to overload the battery. Here the voltage change in the booster should not keep up with the external load change, and the booster should be so designed as to work on the drooping portion of the curve when this point of excess load and consequently high booster field current is reached. In practice, it is usual to provide from 10 to 15 per cent. more of those field turns which are affected by change in current or voltage than the calculated number, and after the machine is installed, a few turns are shunted to bring the operation exactly within the desired limits.

When shunt wound motors are connected across mains or bus bars on which the voltage fluctuates, as is the case when the source of supply is a shunt wound generator, and the external load variable, they show a tendency to "hunt" and do not seem to be stable as to speed. If, however, the motor is specially designed to work under such conditions, by keeping the magnetic density in the field and magnet limbs well below the "knee" of the magnetization curve, and making the air gap small so that the change in field strength is sufficiently great under changes of impressed E.M.F. to compensate for the increase of voltage at the armature terminals; the motors will work very well, and maintain a reasonably constant speed.

Automatic boosters must be wound on frames which are made of good quality of steel or soft iron if reasonable regulation is desired. Fields and poles having high remanence will make a sluggish booster. The reason for this is evident when the hysteresis factor is considered. Refer to Fig. 135 which is a hysteresis loop. Starting from the point zero, the

booster will rise with the load. When the maximum is reached and the external load falls off, reducing to the normal, there is still a voltage tending to discharge, since there is magnetization equal to OC left in the fields which is generating a discharging E.M.F. The booster voltage does not drop to zero until the load has fallen off below the normal, and from O to I the battery is still discharging, though the

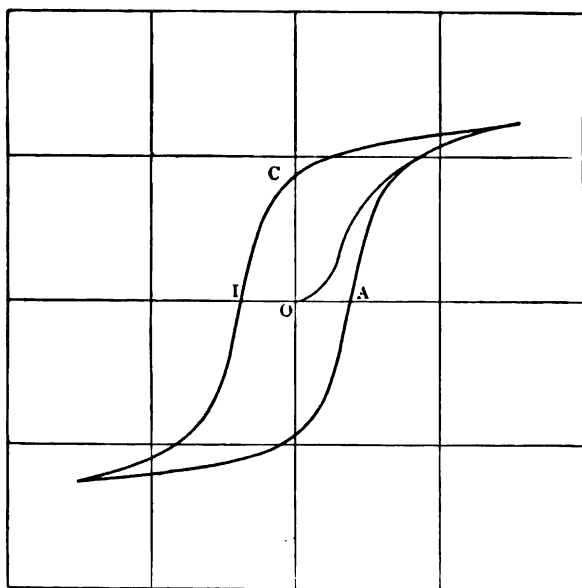


FIG. 135.

load be less than normal. When the maximum on the opposite side is reached, and the load begins to increase, the reverse action takes place. When the load increases up to normal, there is still battery charge and from O to A the battery is charging, though the load is in excess of the normal. This trouble does not affect non-reversing boosters, which always work well up above zero. The foregoing applies only to those which reverse and are continually passing through zero.

While designers of dynamo electric machinery may reason

that the voltage proceeding from this remanence is very small, it must be remembered that at normal voltage of battery and line, and normal load a very small booster E.M.F. will cause a heavy charge or discharge.

From these considerations, it also follows that the booster magnetization should not rise much above the "knee" of the curve, as the remanent magnetization would be increased.

Boosters should always be made as small as the foregoing considerations will allow, for the reason that the efficiency is much greater in a small machine than in a large one, where the same output is required of either.

The selection of a booster depends on

- (1) Type of generating units.
- (2) Average load.
- (3) Maximum load.
- (4) Minimum load.
- (5) Character of service of system.

If the generators are shunt wound, any booster system will work in connection with them, but if they are compounded some of the systems will not operate on lines which they feed, unless the booster is so far away from the generator that the line drop is greater than the over-compounding, as has been previously pointed out.

In systems on which the maximum demand is great, but fluctuating, and the average demand small, the constant current booster is most suitable, since it only carries the average current.

Where the average demand is large, and the maximum is not very much greater than the average, one of the types of booster which is in series with the battery should be used.

## CHAPTER XXXVII.

### RHEOSTATS.

The rheostats used for booster regulation are connected somewhat differently from the usual dynamo and motor regulating rheostat. The reason lies in the necessity of often impressing E.M.F.'s across booster fields of from maximum to zero and sometimes to a maximum in an opposite direction.

Fig. 136 shows the ordinary method of connecting rheo-

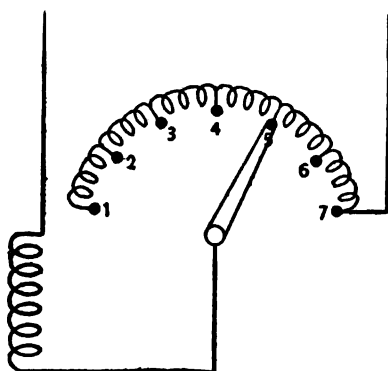


FIG. 136.

stats.  $F$  is the coil or field across which the voltage must be varied. The other connections are obvious.

Now, if the arm  $A$  be moved in to the last contact 1, there is still a current flow through  $F$ , equal to  $\frac{R + R_1}{E}$  in which

$R$  = resistance of the rheostat,  $R_1$  that of the field coil,  $F$  and  $E$  the volts between the mains. Therefore, it is clearly impossible to reduce the voltage to zero with this form of rheostat, and to even approach it requires the resistance be very great and the cost high.



Fig. 137 shows the method most used for connecting booster rheostats. In this case, the resistance coils are connected across the line, and the voltage impressed on F, for any movement of A is equal to the drop through the rheostat coils included in the circuit and when A is on point 1 the voltage across F is zero.

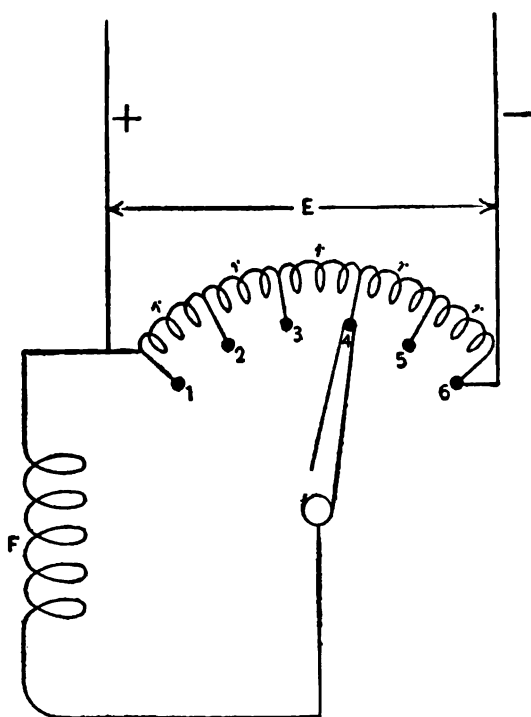


FIG. 137.

A form of rheostat recently invented by the author has the advantage of permitting zero voltage to be attained and, at the same time, prevent the energy loss which takes place across the rheostat coils continuously, whether the booster be in service or not.

This form is shown in Fig. 138. The resistance connections do not differ from those of the ordinary rheostat except that one of the resistance coils is left out and two adjacent

contacts are joined together.  $C$  and  $C_1$  are short copper segments which are connected together by a contact plate on the under side of  $A$ .

When  $A$  is in the position shown by the full lines, the action and connections are exactly as in Fig. 137, and when  $A$  is on contact 1 the potential across  $F$  is zero. When  $A$  moves off of 3 on to 4, the connection across the line through

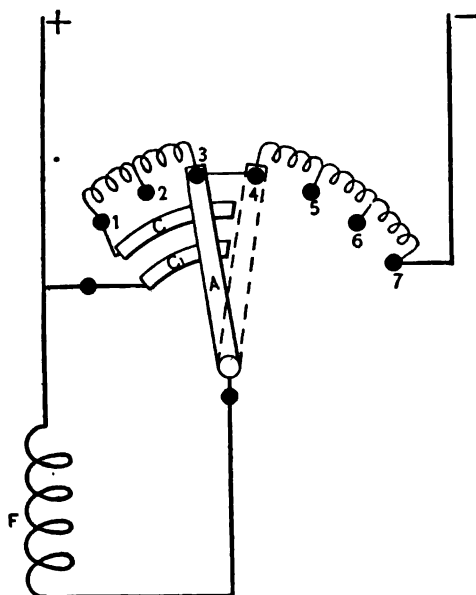


FIG. 138.

the resistance coils is opened, and the rheostat connections become as shown in Fig. 136. In passing from 3 to 4, less current flows through the coils from 4 to 7 because of the opening of the circuit through coils 1 to 3, and a higher E.M.F. is impressed on  $F$ , so that no coil is necessary between 3 and 4 as the volts across  $F$  increase from opening the circuit from 1 to  $C$ .

When it is desirable both to reverse the direction of current flow in the booster fields as well as vary its potential, the rheostat just described, used with an ordinary reversing

switch, will suffice, though reversing rheostats are often used. The scheme of connections of the reversing rheostat is shown in Fig. 139.

$C_1$  and  $C$  are copper segments across which  $F$  is connected

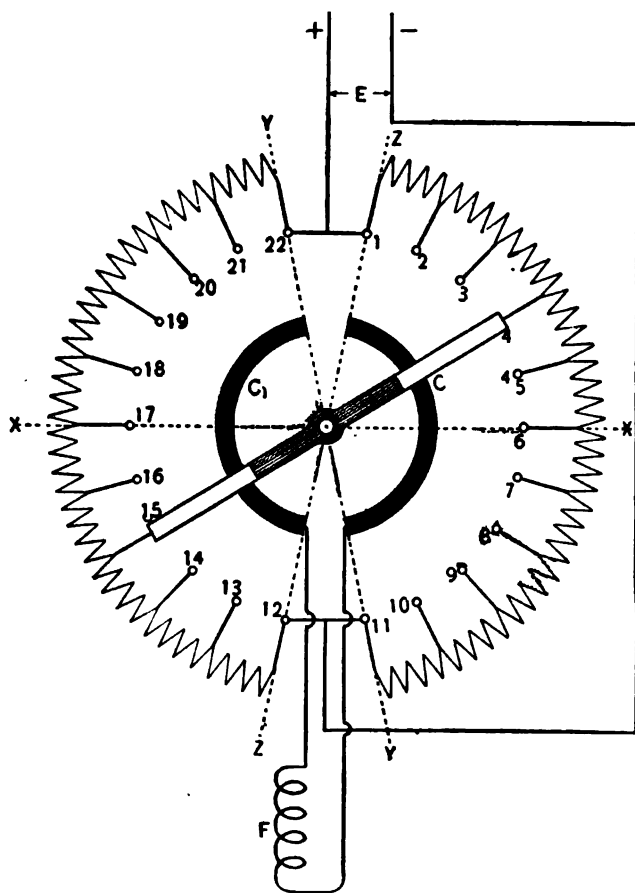


FIG. 139.

and they are joined to contact points by means of the arm  $A$ . The two ends of  $A$  are insulated from each other, and the current travels only from a contact to the nearest segment over the conducting portions of  $A$ .

Movement through approximately 90 degrees varies the

potential across  $F$  from maximum to zero, the first being impressed when  $A$  coincides with the dotted line  $Y Y$  and the latter when it coincides with  $X X$ . After passing  $X X$  the current reverses in  $F$ , and when the arm reaches the position  $Z Z$  the opposite maximum is reached.

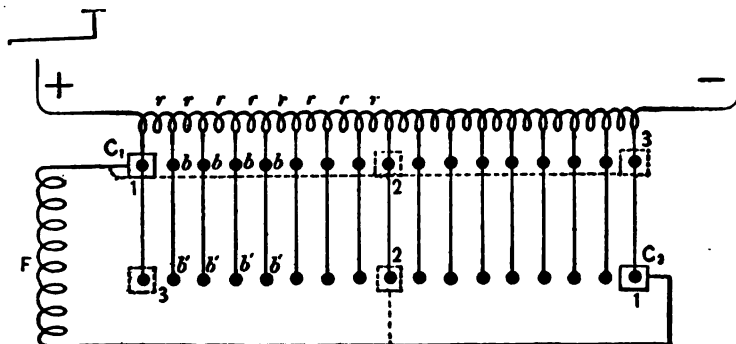


FIG. 140.

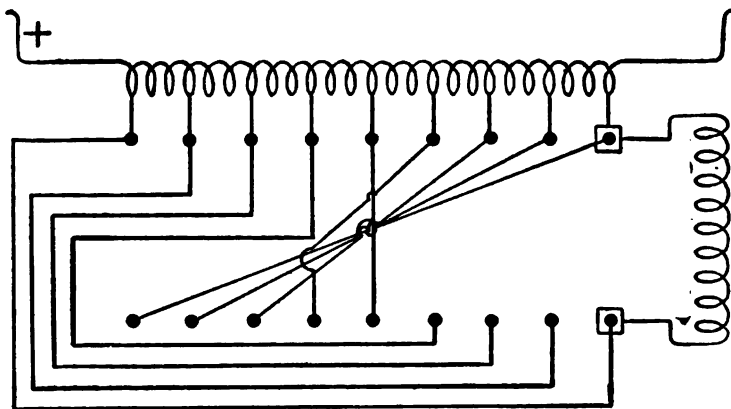


FIG. 141.

This form is somewhat elaborate and expensive and requires a rather large amount of switchboard space. It, therefore, is only installed with the larger sizes of boosters. A cheaper, more compact form of reversing rheostat is shown in Figs. 140 and 141.

Fig. 140 is a diagrammatic sketch explanatory of the con-

nections,  $C_1$  and  $C_2$  are contacts which move along their respective rows of contact buttons  $b.b.b.$  and  $b^1.b^1.b^1$ .  $F$  is the booster field. The resistance coils  $r.r.r.$  are in series across the supply mains.

When the contact pieces  $C_1$  and  $C_2$  are in the position shown by the full lines the voltage across the booster field is a maximum. The contacts move in opposite directions and pass each other midway as shown by the dotted lines at position 2. Obviously the voltage across the booster field at this point is zero. As the buttons continue to travel the current through the coil  $F$  reverses when the contacts pass the middle position, and at position 3 the voltage across the field is a maximum, but in an opposite direction to that in position 1.

In practice, this device is made up of an ordinary rheostat and two contact plates. The contacts are, of course, regular rheostat arms mounted on the same shaft and rotated by the same hand wheel. In this case, the contacts move in the same direction but the desired effect is obtained by connecting the buttons oppositely as shown in the diagram, Fig. 141.

## CHAPTER XXXVIII.

### CIRCUIT BREAKERS.

---

Circuit breakers are used for the protection of the battery, and the machinery with which it is connected.

The overload circuit breaker and its use are so familiar to engineers as to require no description here.

The underload circuit breaker is used to prevent the battery from discharging if the charging dynamo should be shut down or the polarity of the charging source be reversed. This circuit breaker is made in several forms, but the principle of them all is practically the same.

The breaker is held closed by the passage of current, either directly or by holding down a latch. When the current reaches a predetermined minimum, the spring which tends all the time to open the breaker, overpowers the magnetizing force of the diminishing current, and opens it. Since no reversal can take place without the current passing through zero, this breaker effectually prevents such reversal. Usually the underload breaker is intended to be cut out of circuit on discharge, and if it is a polarized instrument, must be cut out as it will not permit a discharge to pass through it. If not a polarized breaker, discharge may be taken through it, but at the beginning and until the current has passed the minimum value, it must be held closed by hand.

The carrying capacity of the underload breaker necessary is that which corresponds to the maximum amperes of charge.

Some boosters, *e. g.*, the compound type, if left connected to the system, and the driving motor circuit be interrupted, the booster will reverse its direction of rotation, and act as a series motor, finally speeding up to the point of destruction. Therefore, when boosters of this character are installed and

the motors provided with overload breakers, there must be a breaker in the booster circuit, which interlocks—either mechanically or electrically—with the motor breaker so that the opening of the motor circuit causes an instantaneous opening of the booster circuit.

In the mechanical device there is a lever connected to the motor breaker which controls the latch on the booster breaker, and is so arranged that in case the motor breaker opens, the lever will operate the catch on the booster breaker, causing it to release and break the circuit.

When operated electrically, the booster breaker, in addition to the usual series coils, is provided with an auxiliary coil, which is generally placed inside the series coil and around the plunger, its terminals being connected to the bus bars through a contact device. This contact arrangement is on the motor circuit breaker, and so arranged that when the motor breaker releases, the moving arm bridges the two contact pieces when it falls back in its open position, thus closing the circuit through the auxiliary coil on the booster breaker, and energizing it. This coil is so designed that the bus voltage will cause the plunger to rise and release the latch, tripping the breaker and opening the booster circuit.

## CHAPTER XXXIX.

### TWO WIRE SYSTEMS.

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There are numbers of methods of arranging batteries to perform the various functions before outlined, and it is possible to give only a few of the most important.

#### *Feeder and Station Regulation.*

The simplest case is that in which the battery is connected directly across the line, and "floats" with the load and line drop, as already described. It may, in this case (1) equalize the instantaneous fluctuations, or (2) carry the peak when the demand becomes steadily greater, or (3) maintain a constant drop on a feeder and therefore keep the line voltage within the limits of change of potential at the battery terminals, regardless of the external load, with the feeder cross section only sufficient to deliver the average current from the dynamo at the prescribed drop.

Batteries so connected work under the best possible condition, so far as their moderate use, prolonged life and low maintenance are concerned, but the maximum rates of discharge and, consequently, maximum work, cannot be secured unless the line drop is considerable. For instance, on a 500 volt circuit with 230 cells in series and a drop of 40 volts on an average load, the maximum charging voltage with a few amperes would be 500 volts, or 2.17 volts per cell, and the minimum line voltage to get discharge when the battery charge is nearly exhausted, is  $235 \times 1.8 = 415$  volts, which represents a variation of 85 volts. Between 2.5 and 1.8 is a variation of .7 volts per cell, and if charged up to 2.5 per cell across a 500 volt circuit, only 200 cells can be placed in series.  $200 \times .7 = 140$  volts = total required line



variation to work the battery up to its maximum limits, and in this case the line drop average must be

$$500 - 2 \times 200 = 100 \text{ volts.}$$

If the battery only regulates the momentary fluctuations, and its state of charge does not materially change, a maximum variation in line voltage of about 40 volts above and below the normal, the total being 80 volts, will cause satisfactory operation and rapid rates of charge and discharge.

From these considerations it follows that a floating battery

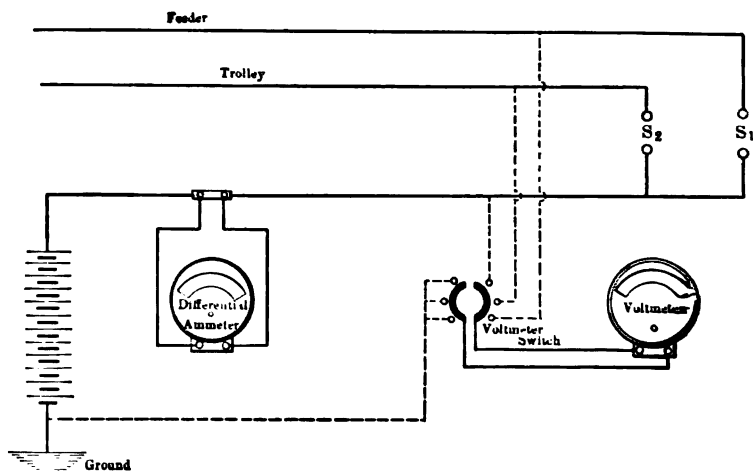


FIG. 142.

at the end of a long feeder is useful for equalizing fluctuations and keeping down the size of feeders, but not for carrying steady peaks.

Fig. 142 shows the switchboard connections of this system at the battery for electric railway service—the only service on which large enough voltage variations to make it operative can be allowed.

$S_1$  and  $S_2$  are independent single-pole, single-throw switches. When  $S_2$  is open, the battery charges only and when  $S_1$  is open it discharges only. The voltmeter and ampere meter, which latter is a two-way reading instrument showing charge or discharge, are not necessary, though convenient. It is

obvious that floating batteries may be used in power stations with shunt dynamos as the source of supply, if these machines have a high armature reaction giving considerable

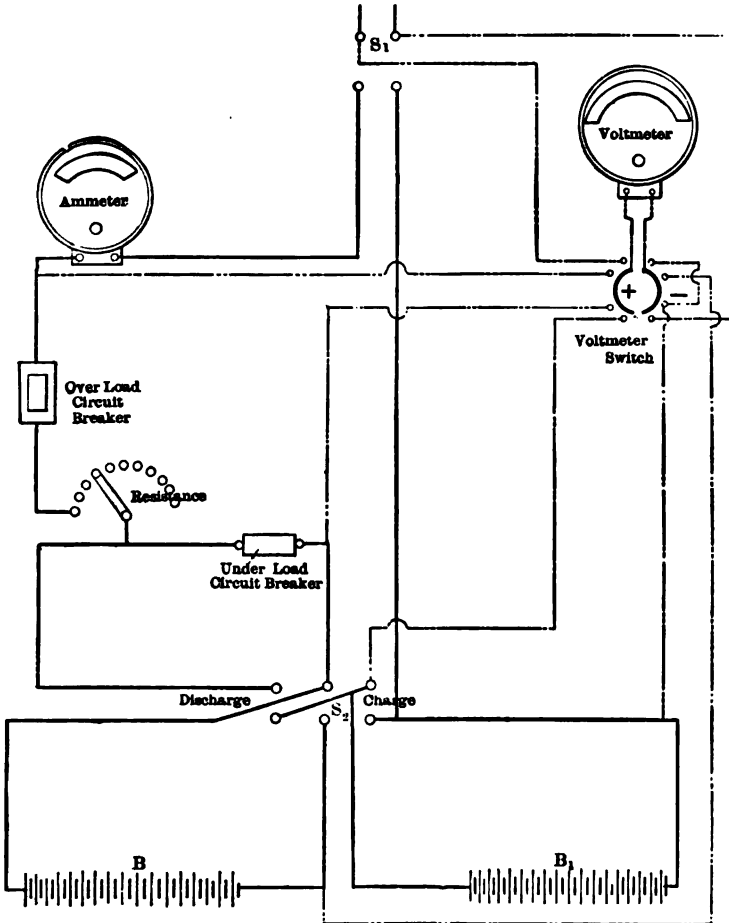


FIG. 143.

change in terminal voltage with change in load, and the wide voltage changes necessary are admissible.

The complete discussion of battery systems for long railway feeders is given in Chapter XLIV.

*Power Storage Systems.*

The simplest case of power storage is that of the small, isolated plant, such as is found in apartment houses or on yachts, where the load from 11 or 12 o'clock P.M. is light enough to be entirely carried by the battery, the generators being shut down.

In Fig. 143 is shown one system of connections by which this is accomplished.  $L_1$  and  $L_2$  are the bus bars.  $S_1$  is a D.P.S.T. switch.  $B$  and  $B_1$  the battery which is separated into two halves, as shown.

$S_2$  is a D.P.D.T. switch connected as shown.

When  $S_1$  is closed and  $S_2$  thrown to the right, connecting the central and right hand contacts, the charging circuit passes into the two halves of the battery, which are in parallel and therefore much below the voltage of the generator. The path of the current is through the ampere meter and overload circuit breaker to the resistance, through which it passes, the current flow being regulated by the resistance.

From the resistance, direct to the left half of the battery and through the upper blade of  $S_2$  to the right half. Passing through these, the current from left half goes via the lower blade of  $S_2$  to the outgoing line which is connected direct to the right half of the battery.

When  $S_2$  is thrown to the left it is in a position to discharge and passes through all the switchboard instruments except the underload circuit breaker. The path of the current can easily be traced, and it is seen that the two halves of the battery are now in series, their voltage being much higher than that of the line. This voltage is reduced by manipulating the resistance through which the current passes.

All the instruments required are shown. This system has the advantage of being simple and cheap. Its disadvantages are loss of energy in the resistance, both on charge and discharge, and the fact that the constancy of voltage or discharge depends on constancy of load, since the current is regulated by the ohmic drop of the resistance.

A modification of this system is shown in Fig. 144. Here

the cells are divided into three groups, which are charged as follows:

Groups 1 and 2 in series.

Groups 2 and 3 in series.

Groups 1 and 3 in series.

Each combination being charged one-half the time re-

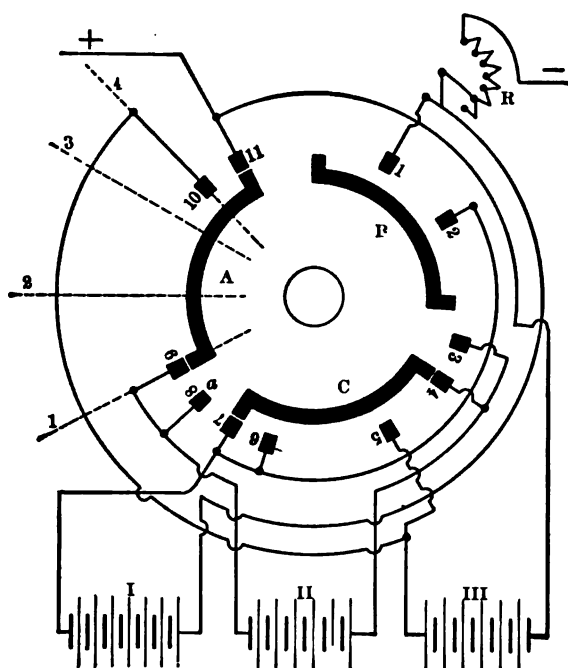


FIG. 144.

quired to fully charge a cell at the rate that current is supplied.

They are all discharged in series.

This latter modification has the advantage of requiring less resistance in series with the charging current, as on charge there are two-thirds of the total cells in series, as compared to one-half, in the preceding case.

Referring to the figure, the switch consists of eleven contacts, 1 to 11 inclusive, and three movable contact pieces,

A<sub>1</sub>, B and C, each having a contact brush or piece at either end. Group I is connected to contact points, 1, 2, 6 and 7. Group II to 3, 4, 8 and 9, and Group III to 5, 10 and 11, the terminals being also connected to 1 and 11. R is the adjustable resistance.

In the position shown, Groups I and II are charging. Calling a the lower end of the moving segment A, the dotted

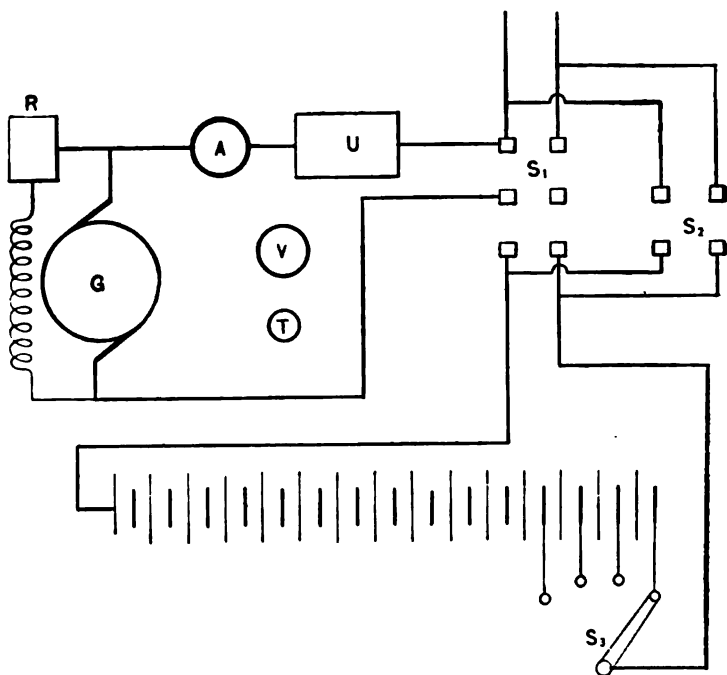


FIG. 145.

lines show the angular position of a around the circle and the connections that are made for each angular position are easily traceable. In position 1, as shown, Groups I and II are in series on charge, in position 2, Groups II and III in position, 3, Groups I and III are being charged in series, and in position 4, all the groups are in series on discharge.

The time of charging in this system is twice as long as required in the single series for the same current rates.

These systems of grouping cells for charging are applicable

only to small plants. Where heavy currents are to be carried, the switching devices become so cumbersome that boosters are cheaper and more easily handled; besides, the saving of the losses in the resistances which, with large currents, would be intolerable.

A system which is almost universally used for country house and private plants in which the generator is driven by a gasoline or kerosene engine, the battery being charged during the day, the current at night being furnished from the battery only, is shown in Fig. 145.

In this, the maximum generator voltage is equal to  $N \times 2.6$ , and the voltage of the line  $= N \times 1.8$ . When  $S_1$  is closed downwards, and  $S_2$  open, the battery is connected for charging, and the current is regulated by varying the generator voltage. This is done with rheostat R.

When  $S_1$  is open, and  $S_2$  is closed, the battery discharges to the line, its voltage being regulated by the end cell switch  $S_2$ .

When  $S_2$  is closed, and  $S_1$  thrown to the upper position, the generator voltage being reduced to equal that of the line, the generator and battery may be made to work in parallel.

No current can be furnished the line when the battery is being charged except at a higher voltage than normal. A is an ampere meter, U an underload circuit breaker, V a voltmeter and T a three-point voltmeter switch connected to show the voltage of (1) the generator; (2) the line and (3) the battery.

Another system of charge and discharge which has the advantage of permitting the batteries to furnish current to the line while being charged, is shown in Fig. 146.

As is seen, there are nine counter E.M.F. cells connected in series with the battery. The charging current goes in over  $S_1$ , passing through the resistance which regulates it. The voltage of the generator is higher than that of the service bus bars, the excess reaching .7 N volts at end of charge, in  $N$  = number of cells in series.

The current to the line, however, passes through the counter E.M.F. cells and  $S_2$ , the opposing voltage cutting

down the generator E.M.F. to the proper amount. This is regulated by the number of counter cells in the circuit which are cut in as the generator voltage rises. The number of counter cells required  $= \frac{.7N}{2} = .35 N$  where  $N$  = number of main cells in series.

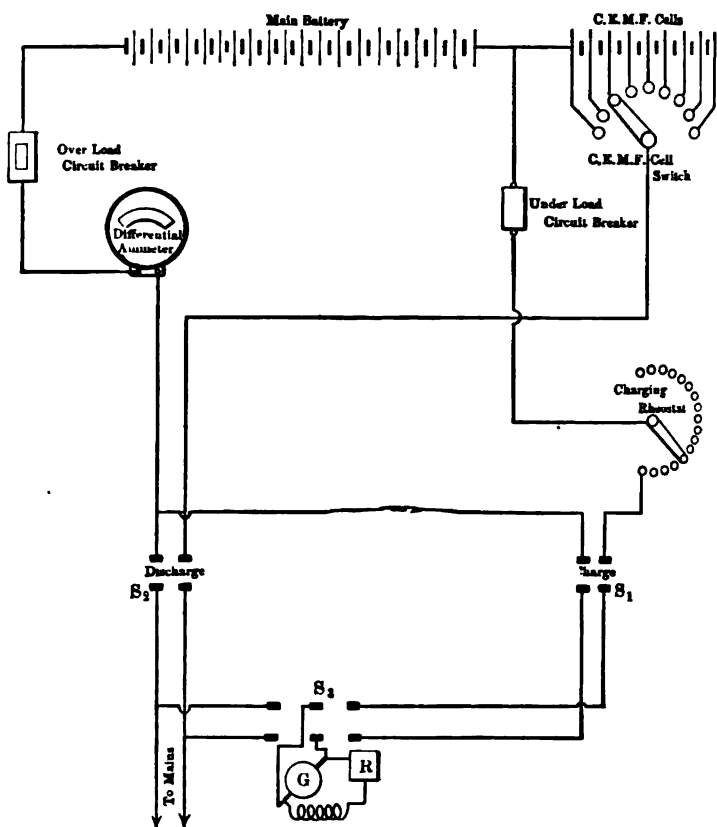


FIG. 146.

The double-pole, double-throw switch,  $S_2$ , when thrown to the right, connects the generator to the battery system and through the C.E.M.F. cells to the line. When thrown to the left, the generator is connected directly to the line, its voltage

of course being reduced by the field rheostat  $R$  to that of the line, and the battery may then be discharged in parallel with  $G$  to carry a peak. When  $S_2$  is open the battery carries the entire load.

This system, in common with all counter E.M.F. cell systems, is practically obsolete, as better results can be obtained by using certain of the battery cells as end cells. The

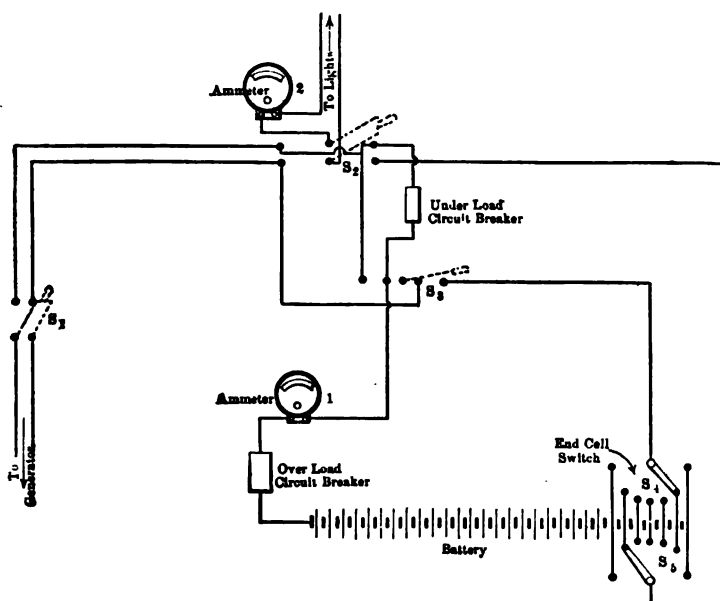


FIG. 147.

use of counter cells does not reduce the number of cells required in the battery, and the expense of the equipment is increased by the addition of counter cells, and they are also an additional complication.

There is one class of plant only where C.E.M.F. cells are suitable, and that is the isolated plant which is charged up during the day by an attendant who either does not stay in the station or who has not sufficient intelligence to cut out the battery end cells as they are charged full. With the C.E.M.F. cells the plant may be left to work itself on charge



and without attention, if the supply circuit be left open. If current is used on the external circuit while charging proceeds, the attendant must be on hand to cut on counter cells,

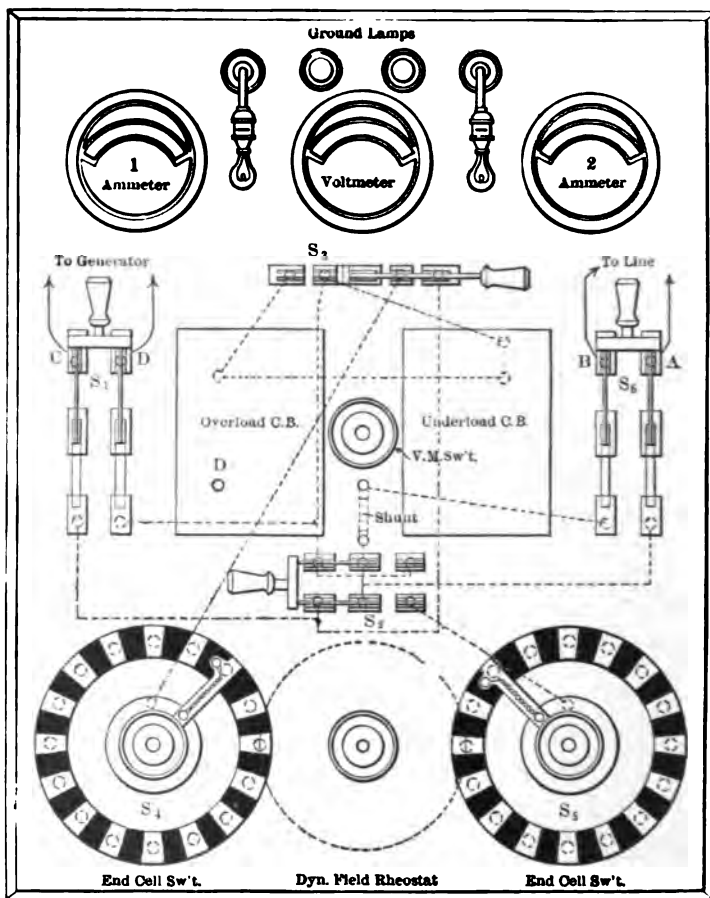


FIG. 148.

otherwise the external voltage will rise far above the normal.

The best of the systems which operate without boosters is that shown in Fig. 147. There are two end-cell switches, the similar points of each being connected to the same end cell, as shown.

The current from the generator goes through the switch  $S_1$  to the left-hand terminals of the D.P.D.T. switch  $S_2$ . When  $S_2$  is thrown to the left position, the battery is cut out of service entirely. One of the generator leads is permanently connected to the left battery terminal passing through the underload circuit breaker, two-way reading amperemeter and overload breaker. The other generator lead is connected to the end cell switch by the double break, S.T., S.P. switch  $S_3$ , when it is in its position to the right.

When the battery is charging,  $S_2$  and  $S_3$  are thrown to the right. The generator voltage must be in excess of that of the line by an amount sufficient to force current into the cells. All current to the line passes through the end cells included between the contacts of  $S_4$  and  $S_5$ , on which the respective arms of these two switches rest, and the line voltage is less than the generator voltage by an amount equal to the voltage of the number of cells in series between these two contacts. With  $S_2$  on the right hand, and  $S_3$  on the left hand contacts, the underload circuit breaker is cut out and the battery ready to discharge, either in parallel with the generator, or alone if  $S_1$  be opened.

This system has the advantage over the preceding one of requiring no additional counter cells, though the end cells in this case must be sufficiently large to pass the sum of the external current, and charging currents through them. In nearly every case in practice the end cells need not be increased above the size of those in the main battery.

Fig. 148 shows the switchboard for this system, the connections being indicated by dotted lines. The switches and amperemeters on it are numbered to correspond with those shown in the diagrammatic view. In addition, there is a switch,  $S_6$ , which opens the line circuit.

In all the foregoing systems the generators should be shunt wound, or if series machines, should have a cell put in the series winding as explained in Chapter XXXII.

## CHAPTER XL.

### TWO-WIRE SYSTEMS AND BOOSTERS.

---

The simplest case of the application of boosters to storage battery plants, is that of the shunt booster, in a station where the battery is used for storage only. Such a system is diagrammatically shown in Fig. 117.

The booster field is excited from the generator as shown. With  $S_2$  in the lower position the battery is charging. When thrown to the upper position the booster is cut out and the battery discharges, the voltage being regulated by the end cells and switch  $S_4$ .

If the booster is used reversibly, the end cells and end cell switch  $S_4$  are not required, though the size of the booster is increased, as explained in a previous chapter.

The connections would also be changed slightly.  $S_2$  would require no upper contact and the leads to the booster field would have to be connected to the bus bars beyond  $S_1$ .

Usually this system is much cheaper to install and is higher in efficiency than the systems without boosters, unless the plant be a very small one.

This becomes evident when it is remembered that the generator must be capable of giving a higher voltage than the line when no booster is used, unless the cells be arranged for parallel charging and the charging current, controlled by an energy consuming resistance. The K.W. capacity of the generator is therefore increased. Sometimes this increase is just sufficient to require the next larger size of standard frame, in which case the increased generator cost would be very much greater than that of booster and driving motor. In addition, switches and leads are often saved, all of which are expensive and contribute to make the cost of no-booster systems excessive, as compared with those in which boosters are used.





Plate IV shows a complete switchboard for this system. In addition to the instruments shown in the diagrammatic sketch; over and underload breakers, watt-meters and rheostats for booster and dynamo fields are included;  $S_2$  is double instead of single pole to take in the watt-meters. On charge,  $S_2$  is thrown to the right, putting one watt-meter and the underload breaker in circuit. On discharge, these are cut out by throwing  $S_2$  to the left, which, at the same time, puts the other watt-meter in circuit.

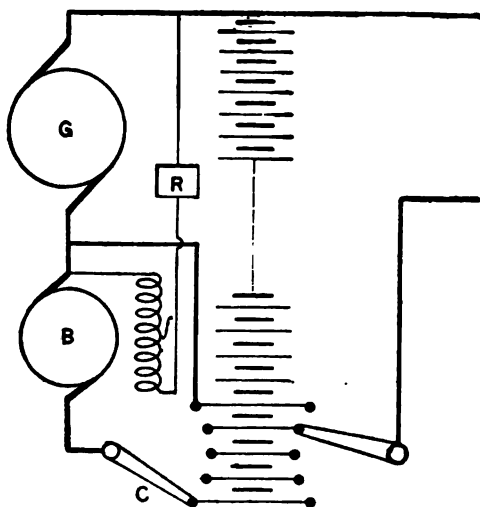


FIG. 149.

The voltmeter and voltmeter switch are not shown but the connections should be such as to show (1) voltage across the bus bars; (2) voltage of bus bars plus booster; (3) voltage of battery. Before beginning charge the switch  $S_2$  is opened,  $S_1$  closed and  $S_3$  thrown to the right-hand contacts.

The booster voltage is then brought up to such a value that bus bar plus booster voltage = about 10 volts more than battery voltage. Then  $S_2$  is closed and the charging current adjusted by slowly raising the booster voltage.

Another system, in which a shunt booster is used on charge, is shown in Fig. 149. In this, the generator voltage

is equal to that of the line and the number of cells in series across the line is regulated by the right-hand end cell switch. The booster *B* is connected between the first end cell adjacent to the main battery and the moving arm *C*. Any number of the end cells may be included between the arm

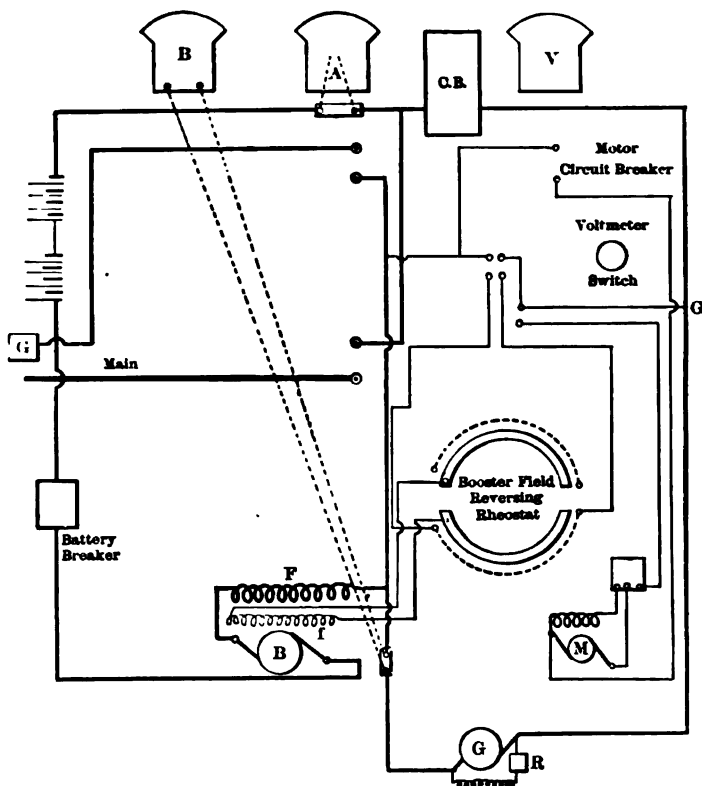


FIG. 150.

and first cell. The function of the booster is to charge the end cells, the voltage of the line being sufficient to charge the main battery. This system is practically obsolete, and has never come into use in this country. The additional cost of the extra end cell switch, and the fact that it has no advantages over the ordinary system have prevented its ever taking a place as a commercially successful system.

*Storage and Regulating Batteries Using Automatic Boosters.*

The use of the various automatic boosters has been explained in the discussion of each so it is not necessary here to go into detail as to the various ways in which they may be installed.

Fig. 150 is a skeleton outline of the connections, instruments and arrangement of switchboard for a battery plant on an electric railway system, and used with a compound

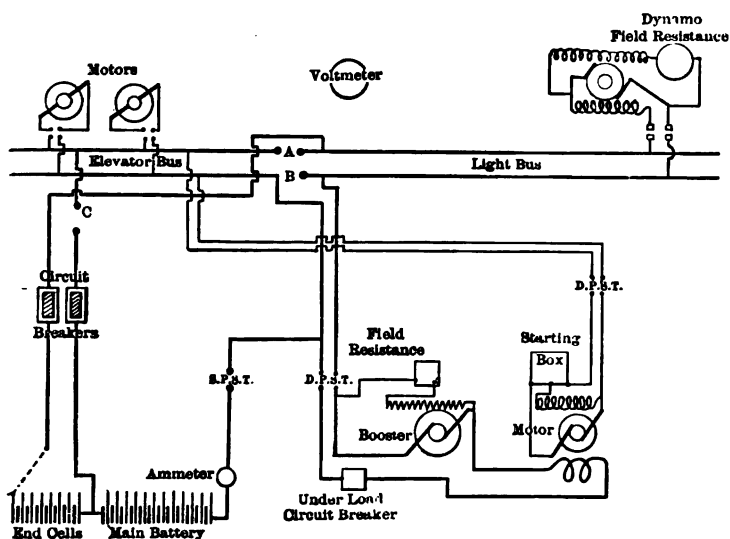


FIG. 151.

booster. A is a two-way reading ampere meter in the battery circuit, B a one-way instrument in the generator circuit, and V is a voltmeter. To avoid confusing the diagram the voltmeter and voltmeter switch connections are not shown. The voltmeter switch should have three pairs of points, the first giving the voltage between generator terminals, the second the voltage of generator plus booster and the third, the voltage of the battery.

Fig. 151 shows the diagram of connections of a constant current booster system with the end cells connected to the lighting bus bars. When switch B is closed, the booster is



cut out and the battery discharges in parallel with the generator, or if the generator be shut down the battery carries the entire load of both lights and power. With B open, the battery takes up the fluctuations in the power load, the generator current remaining constant. When the battery switch C is opened, and A and B closed, the lights and motors are on the generator with the battery in parallel. A must never be closed until C is opened, as the end cells would be

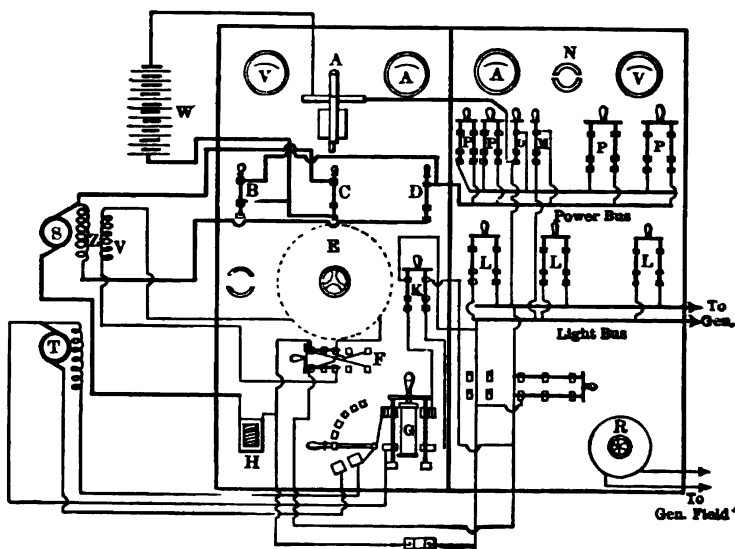


FIG. 152.

short circuited. A and C should be made interlocking or a single-throw double throw switch used.

Fig. 152 is the complete skeleton of a switchboard which controls a constant current system, but which is without end cells. Referring to the diagram:

A is an overload circuit breaker.

H, underload circuit breaker.

G, motor starting box.

F, booster field switch by means of which the magnetization can be reversed.

V, booster shunt field.

Z booster series field,  $S_1$  the booster armature, T the driving motor, E and R rheostats in the booster and generator shunt fields, respectively. The other connections are easily followed out.

When operating under normal conditions, switches C and M are opened, the others remaining closed. C short circuits the booster series field, and M cuts out the booster entirely by joining the power and lighting bars together.

Fig. 153 shows a switchboard scheme for the differential booster. The combinations possible with this system, are

(1) Generator feeding directly to the line, booster and battery out of service. Close  $S_2$  and  $S_3$  upwards,  $S_6$  and  $S_8$ .

(2) Generator and battery in parallel with bus bars, booster out of service. Close  $S_1$  upwards and  $S_7$ , in addition to those in (1).

(3) Booster in series with the battery, series coils operating battery and booster across the line. This is the normal condition of operation. Close  $S_1$ ,  $S_2$  and  $S_3$  downwards,  $S_4$ ,  $S_6$  and  $S_7$ .

(4) Booster in series with the battery, series coils short circuited, battery charging only. Close  $S_1$  downwards,  $S_4$  and  $S_5$  upwards,  $S_6$ ,  $S_8$ ,  $S_9$  and  $S_7$ .

This system is suitable for railway work, and if the negative bus bar be connected to the ground, and the positive carried on to the feeder panels, the diagram will show the method of installing in connection with electric railways.

Fig. 154 shows the connections for large power station in which both light and power are used. The generators may be thrown on to either the light or power bus bars. The regulating booster shown is the C.E.M.F. exciter booster. In this diagram the instruments have been omitted, but they are practically the same as in the foregoing diagrams.

B is the booster, R the counter E.M.F. exciter and M the driving motor. It is to be noted that the motor and booster circuit breakers are interlocking. If the motor circuit should open, the field switch of B is also opened, otherwise it would run as a motor without excitation other than that from the armature current and speed up to destruction. The contingency in this case, however, is very remote.

The storage battery is convenient in a power station where two or three bus bar pressures are carried. Fig. 155 shows one method of accomplishing this with one generator only.

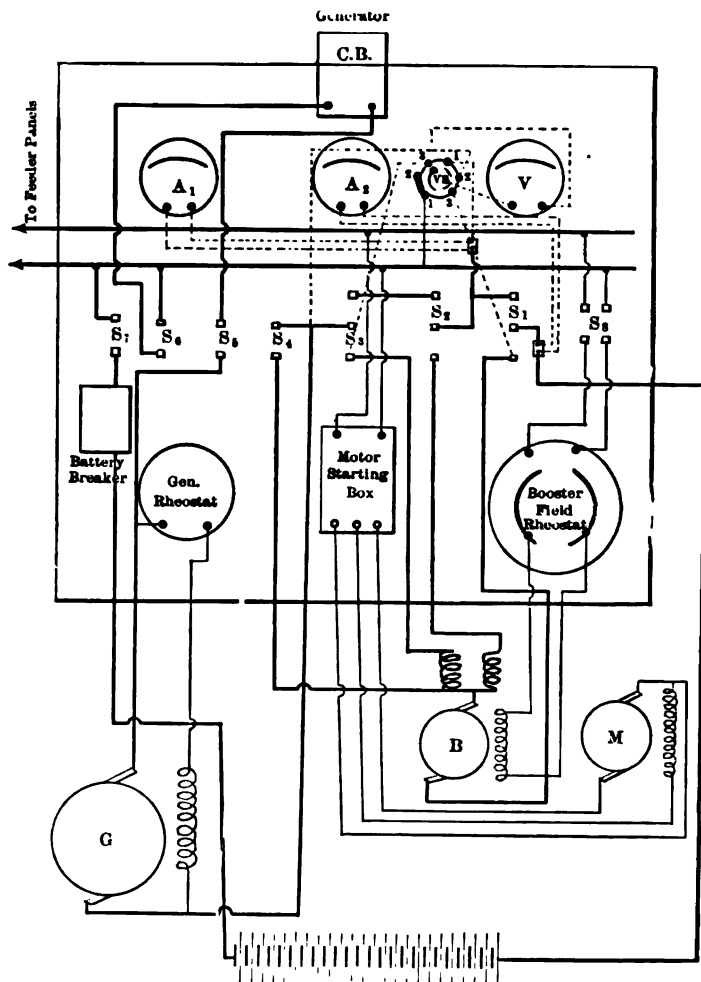
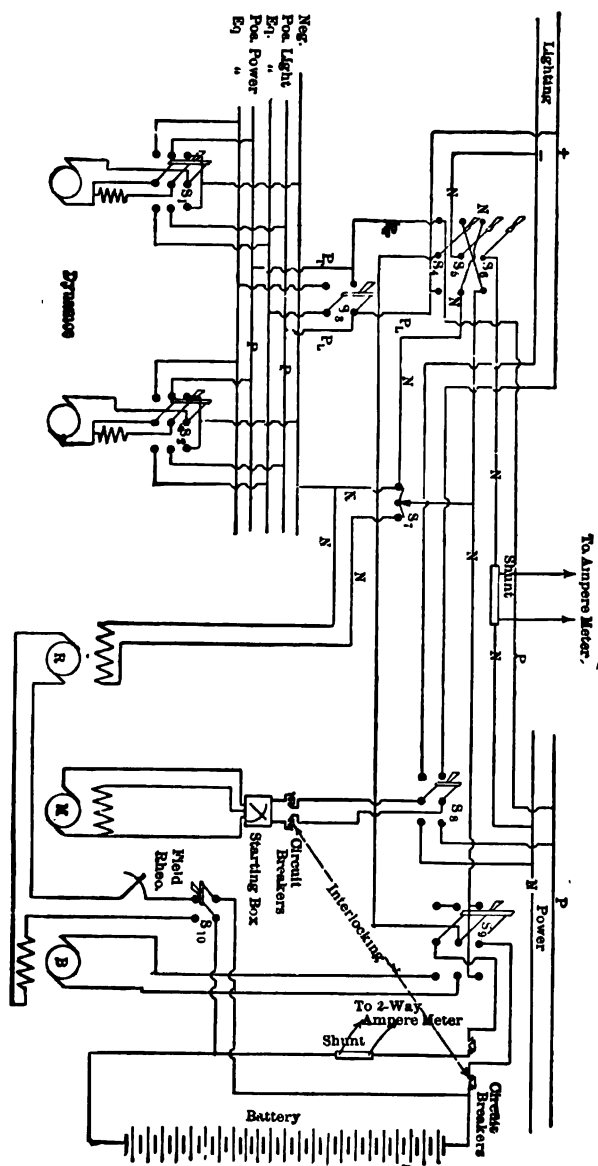


FIG. 153.

The maximum generator voltage must be equal to  $2.6 N$  and the line voltage between outsides adjusted by means of the end cell switch.



**FIG. 154.**

The medium and low pressure bus bars have each a two-point end cell switch connected to the battery cells.

A better arrangement is shown in Fig. 156, where the generator gives the normal bus bar voltage and the higher bus bars have cells between them and a booster in series with these added cells.

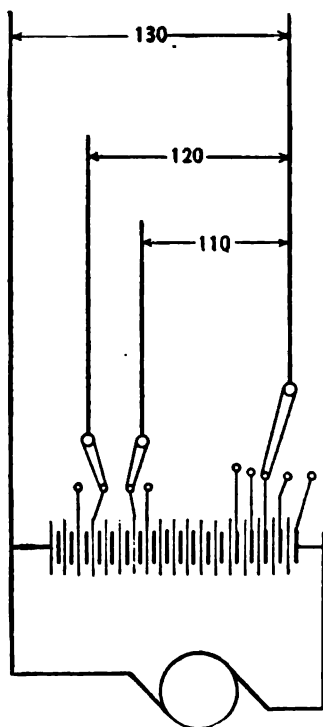


FIG. 155.

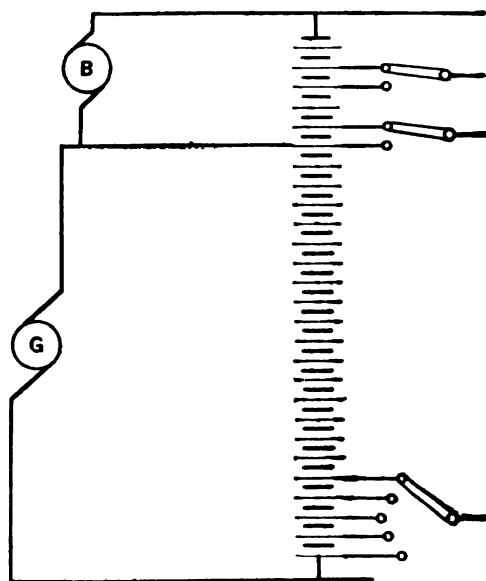


FIG. 156.

### *Regulation of Long Feeders.*

It sometimes occurs, particularly in the case of railway circuits, that it is desirable to locate the battery out on the line some distance from the power station and yet avoid having any equipment at that point requiring continuous attention. There are many schemes for locating the booster in the power station and regulating the battery. One of the best of these methods is indicated in the diagram, Fig. 157.

The compound wound motor, constant current booster is used and keeps the current flowing through the feeder constant, the battery taking up all load fluctuations.

The constant current systems lend themselves to this par-

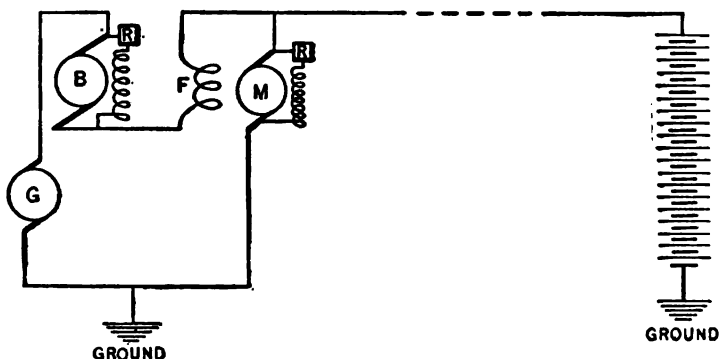


FIG. 157.

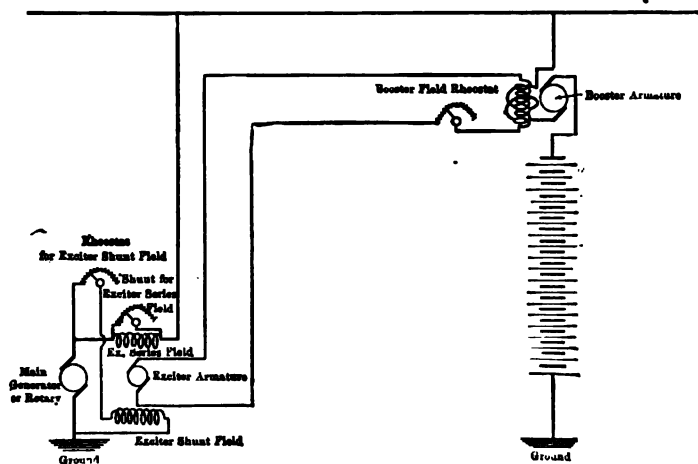


FIG. 158.

ticular class of work without additions and complications and therefore are best adapted to situations of this kind.

Another method of regulating discharge on long feeders, and at the same time maintaining a practically constant voltage, at the point where the battery is connected, is shown herewith in Fig. 158.

The booster, which is a separately excited machine, is placed in the battery substation, while the exciter is placed in the main station. No special feeder is necessary from the main station to the substation, only the two exciter wires which carry but a few amperes—from 8 to 12, in practice, with a 50 K.W. booster.

In this case, the exciter has a shunt coil as well as the usual series winding the two being in opposition. The resultant magnetization is zero at normal load, changing up or down with variation of load, and correspondingly changing the current in the exciter field, both in direction and intensity. The net result, of course, is to produce a booster E.M.F. of such magnitude and in such a direction as will cause the battery to meet the load changes.

The booster is provided with a few series turns in addition to the regulating exciter coil. The series coil produces always a M.M.F. which opposes that of the externally excited coil. The object of this opposing series winding is to limit the battery discharge or charge when the load changes greatly from the normal. In such cases, the generator must work at an over or underload rate for the time during which the excessive load or very slight load may last.

As mentioned previously, this limiting effect can be produced by winding booster to work up to the knee of the magnetization curve, and when this limit is reached, the voltage will not increase proportionally to the load.

## CHAPTER XLI.

### THREE-WIRE SYSTEMS

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Fig. 159 shows a battery connected on a three-wire system acting both as an equalizer and for power storage.

There are an end cell and a booster at each end of the system, and the algebraic sum of the generator plus two booster voltages is always equal to that of the battery.

The kind of boosters required depends on the character of the load. If the battery is to give regulation on fluctuating loads, some type of automatic booster which maintains the line voltage constant, must be used. If the boosters are merely for charging, the ordinary shunt machine is suitable. If the boosters are used reversibly, no end cells nor end cell switches are required.

As seen in the figure, the neutral wire is connected to the middle point of the battery, when  $S_1$  and  $S_2$  are closed in either direction. This is the fixed point to which the other leads must be referred and the individual voltages on each side are adjusted with reference to the neutral, not to the voltage across the outsides. Of course, when the voltage on each side is correct, the voltage between the outsides is also correct, but it is obvious that the voltage between outsides might be normal and yet an inequality exist between the two sides of the system.

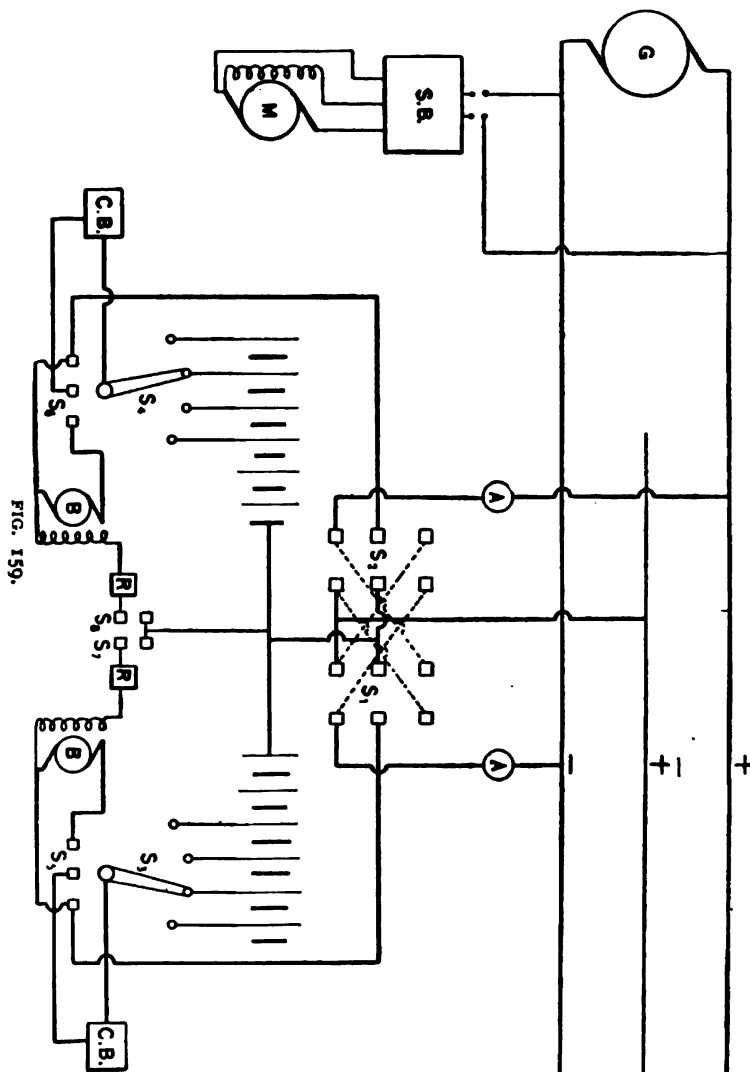
$S_3$  and  $S_4$  are single-pole, double-throw switches, by means of which the battery may either be connected to the line direct, or through the booster.

$S_1$  and  $S_2$  are D. P., D. T. switches, connected as shown.

When  $S_1$  and  $S_2$  are closed on the lower contacts, the left-hand half of the battery is across the positive and neutral, while the right-hand half is across the neutral and the negative. If one side of the system should be more heavily



loaded than the other, and therefore take more charge from its half of the battery, the switches  $S_1$  and  $S_2$  may be closed



on the upper contacts and each half of the battery transferred to the opposite side of the system. In this way, the

battery discharge may be equalized, whatever the difference in requirements of the two sides of the system.

Although this arrangement offers many advantages, the neutral is usually directly connected to the middle point of the battery. Wherever the load has an appreciable unbalance factor,  $S_1$  and  $S_2$  should always be installed.

In this system, the entire battery may be charged in series, or either half separately, and may serve as an equalizer while charging, but cannot work in parallel with the generator during charge, unless an automatic reversible booster be used.

The necessary instruments and their positions in the line are indicated except the generator instruments and the voltmeter and voltmeter switch with the connections of the latter.  $A, A$ , are two-way reading ampere meters,  $S_1$  and  $S_2$  end cell switches,  $M$  the motor,  $U$  the underload circuit breaker,  $CB$  and  $CB$  the battery overload breakers, and  $S$  the motor starting box.

The switches are all indicated.

The voltmeter switch connections are as follows: (1) voltage of outsides; (2) and (3) voltage of each outside to neutral; (4) voltage across battery; (5) and (6) voltage across each half of the battery; (7) voltage of outsides plus both boosters; (8) and (9) voltage of each side plus the booster on that side. When charging the total battery, at the beginning, the voltage reading (8) should exceed (4) by about 10 volts, before the switches  $S_1$  and  $S_2$  are closed. The charging current is afterward brought up to normal by means of the booster rheostats. While the charging takes place, the readings of 8 and 9 should be maintained equal by adjusting the booster rheostats. When charging each half the battery separately, the sum of the line plus booster voltage should exceed that of the half of the battery by about 5 volts before closing the switch  $S_1$  or  $S_2$ .

The breakers in the battery circuit prevent the battery from discharging at a rate higher than that for which they are set.

In diagram, Fig. 160, is shown a method of connecting a battery to a three-wire system where the office of the battery

is to act as an equalizer and also store energy at the time of light loads to carry the heavy peaks.

A and A are two-way ampere meters.  $S_1$  and  $S_2$ , D. P., D. T. switches, C, B, circuit breakers,  $S_3$ ,  $S_4$ ,  $S_5$  and  $S_6$  end cell switches. R, booster field rheostat, B, the booster, M, the motor, C, the motor starting box, and  $S_7$  and A, a switch and ampere meter, respectively, in the booster circuit.  $S_1$  and  $S_2$  admit of changing the halves of the battery to either side of the line, as described in the preceding case.

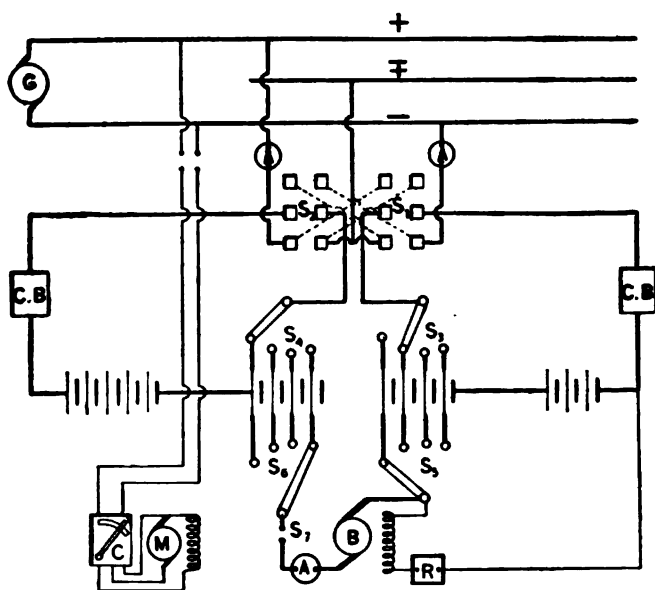


FIG. 160.

In this system, a single booster only is used, which charges the end cells. If G is shunt wound, the battery will partly take up fluctuations on the outside circuit, but is not so well suited for this as the system just before described. Also the K. W. capacity of the booster in this case must be equal to the sum of the capacities of the two boosters used in the previous case, and here two end cell switches are added. Therefore, there is but little to recommend this system in comparison with the other one.

A third method of connecting on three-wire systems is that shown in Fig. 161. In this, the instruments, switches, etc., are the same as in the preceding cases, except that  $S_1$  and  $S_2$  are replaced by  $S_3$ . The two booster armatures are

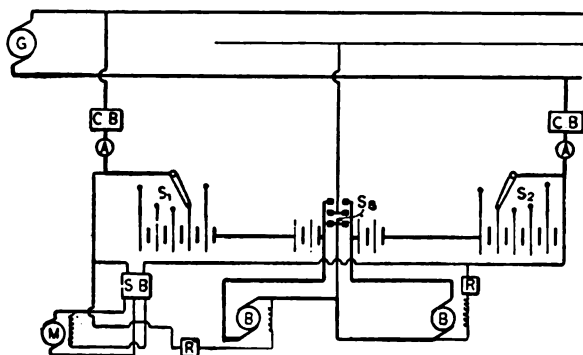


FIG. 161.

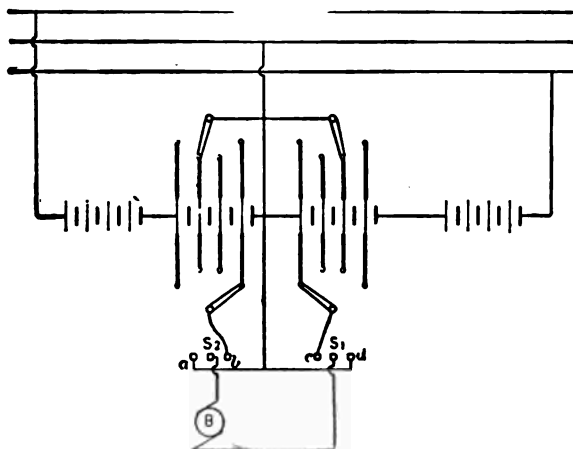


FIG. 162.

in series between the two halves of the battery, as shown, and the connection to the neutral is made from the series connection between the two armatures. This is an excellent and widely used method.

The single booster system shown in Fig. 162 is a modification of diagram Fig. 160. The scheme of connection only

is shown, the instruments and motor being omitted in order that the connections may the more easily be followed out. The motor is connected across the outsides and the instruments and their location are identical with those of Fig. 160. The advantage of this system over that shown in Fig. 160 is that either half of the battery may be charged independently of the other, or the whole battery may be charged in series.

When  $S_1$  is closed on d and  $S_2$  on b, the booster is assisting to charge the left-hand half of the battery. When  $S_1$  is closed on c and  $S_2$  on a, the right-hand half is being charged, and the entire battery is charged connected across the line with the booster in series, when  $S_1$  is on C  $S_2$  on b. When charging either half of the battery alone, care must be taken never to close  $S_1$  or  $S_2$  until the booster has come up to voltage. If there should be no booster E.M.F. when  $S_1$  or  $S_2$  is closed, the end cells included between the upper and lower contacts on which the respective arms rest would be short circuited.

Any of the uses to which a battery is put on two-wire systems may also be realized on three-wire systems, and, in addition, it can be made to act as an equalizer on systems where the generators are connected across the outsides with the single exception of the case where lighting and power are furnished from the same generators, but distributed from separate sets of bus bars, the battery taking the power fluctuations. Where this case arises, the only use of the battery is to take up the power fluctuations, but it cannot at the same time act as an equalizer to compensate for unbalancing of the system.

It is not necessary here to give further examples of connections to three-wire systems, since any application can be made by calculating the booster and battery equipment for one side of the system as though it were an ordinary two-wire system. Doubling the equipment and placing the two halves in series across the outsides with the neutral running between them, completes the scheme of connections. In the case of the driving motors, it is in nearly every instance, practicable to use only one motor to drive both boosters.

This motor is invariably connected across the outsides. It is also to be remembered that the voltage between the neutral and each of the outsides is to be kept constant and a maintenance of the proper voltage between outsides is not necessarily the equivalent. Therefore, all apparatus for voltage adjustment must relate to varying the potential between the neutral and the outsides and not simply the E.M.F. across the outsides.

## CHAPTER XLII.

### ALTERNATING CURRENT SYSTEMS.

---

It is obvious that the only way in which storage batteries can be used on alternating current systems, is through the intermediary of some commutating device. Dynamic rectifiers have never become commercial machines, except in very small sizes, for minor uses, and the low efficiency of the electrolytic rectifier makes its use quite impossible except for very small currents where considerations of efficiency do not enter into the problem.

The only way in which storage batteries can be put on alternating current systems, is to operate in connection with rotary converters, or motor generators. In this case, the source of energy, so far as the battery equipment is concerned, is a continuous current commutator and the applications are exactly the same as given in the preceding chapters.

In a few cases, the rotaries are run to charge the batteries during periods of light load, and when the peaks come on the A.C. system, the batteries discharge back through the rotaries, thus acting as a source of alternating current energy. In such cases the usual protective devices which, in event of interruption of the A.C. current, prevent the batteries from driving the rotaries as series motors and speeding them up to the bursting point, are not applicable, for the reason that the current must flow both to the rotary and from it. Therefore, a special form of circuit breaker must be used which is in series with the battery circuit, but which is held closed by a latch that is kept in place by the action of the alternating current. In multiphase work, this device is best made in the form of a very small induction motor, with a rotor of about 2 inches diameter. The rotor tends to turn but is opposed by a spring. When the A.C. current passes

through the stator, the torque set up in the rotor overcomes the spring, and holds the circuit breaker latch in place. If the A.C. current should be interrupted, the spring turns the rotor backwards through a few degrees, releasing the catch and allowing the breaker to open.

In designing the small induction motor it must be remembered that the slip is 100 per cent.

The principal use of batteries, however, with A.C. systems, is to take up the fluctuations on the continuous current side of rotaries. They steady the demand at the power station, and make possible the operation of 60 cycle rotaries on widely fluctuating loads.

Whenever the load on a rotary converter changes, the armature also shifts its angular position, lagging more or less behind the position of no load. Sudden changes or fluctuations cause corresponding changes in the angular position of the rotary armature. The higher the frequency, the greater is the number of poles and hence the smaller the angle from one pole to the next. Therefore on high frequency rotaries, the allowable angular deviation of the armature from its normal position of full load is exceedingly small, and fluctuations of external load set up oscillations which are known as "hunting." The battery keeps the load constant on the rotary, taking up the variations in its own circuit, and therefore effectually prevents "hunting," and kindred troubles.

Fig. 163 shows the connections and instruments required where the battery is installed to regulate fluctuations and carry the load peak on the D.C. side of a three-wire system supplied by a rotary converter which is connected across the outside mains. In this case, the neutral is connected to the middle point of the battery, and also to the middle point of the secondary transformer windings, as shown.

w.w.w.w. are the incoming high tension wires of a two-phase transmission line. They pass through the fuses F.F.F.F. and oil switches X.X. to the static transformers  $T_1$ ,  $T_2$ .

The secondaries of the transformers are connected to the collector brushes of the rotary converter as indicated.  $F_1$  is



the series field of the rotary which is regulated by the variable shunt  $P$ .  $f_1$  is the shunt field regulated by rheostat  $R$ .

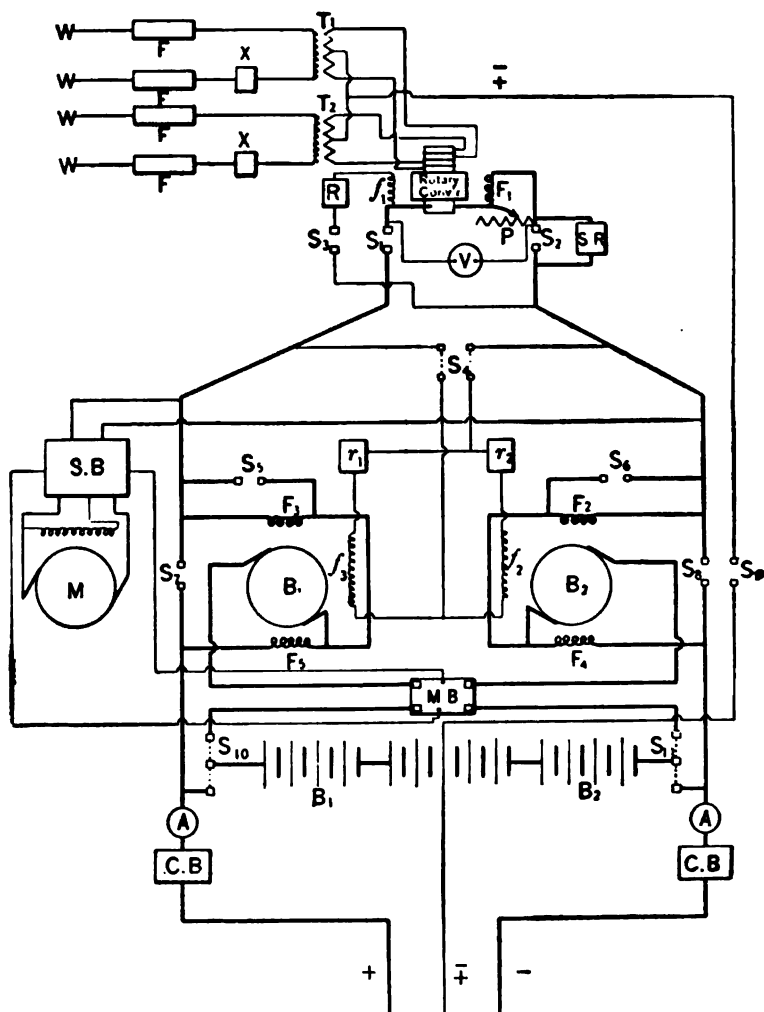


FIG. 163.

The voltmeter,  $V$ , is across the line, but connected on the upper side of the switches  $S_1$  and  $S_2$ . Shunted around  $S_2$  is  $S.R.$ , which is the starting rheostat which is used in bring-

ing the rotary up to speed, the machine being started as a direct current motor receiving its current from the battery.

S B and M are the starting box and motor, the latter driving the two differential boosters  $B_1$  and  $B_2$ .  $F_s$  and  $F_s$  are the series fields of booster  $B_1$ ,  $f_s$  its shunt field, which is regulated by rheostat  $r_1$ .  $S_s$  is the switch by which the series coils are cut out of circuit when necessary to charge or "boil" the battery.  $S_7$  closes the line past the booster, cutting it out entirely.  $S_{10}$ , when closed on the upper contact, connects the battery to the line through the booster. When closed on the lower contact the battery is connected directly to the line.

From the battery the line passes on through the ampere meter A and automatic circuit breaker C.B. to the supply network.

The connections of  $B_2$  are exactly similar.

A four-pole breaker M.B. is shown, which connects with the motor starting box or motor circuit breaker, by two small wires. The opening of this breaker opens both the booster circuits. The device is so connected to S.B. that if the motor circuit breaker should open M.B. will also open. Therefore, if the motor circuit should open from any cause, it would be impossible for the battery to run the boosters as series motors.

## CHAPTER XLIII.

### COMPUTATION OF BATTERY CAPACITY.

In order to compute the size of battery necessary to perform certain work, it is necessary to plot a load curve showing the current consumption at any time during the twenty-

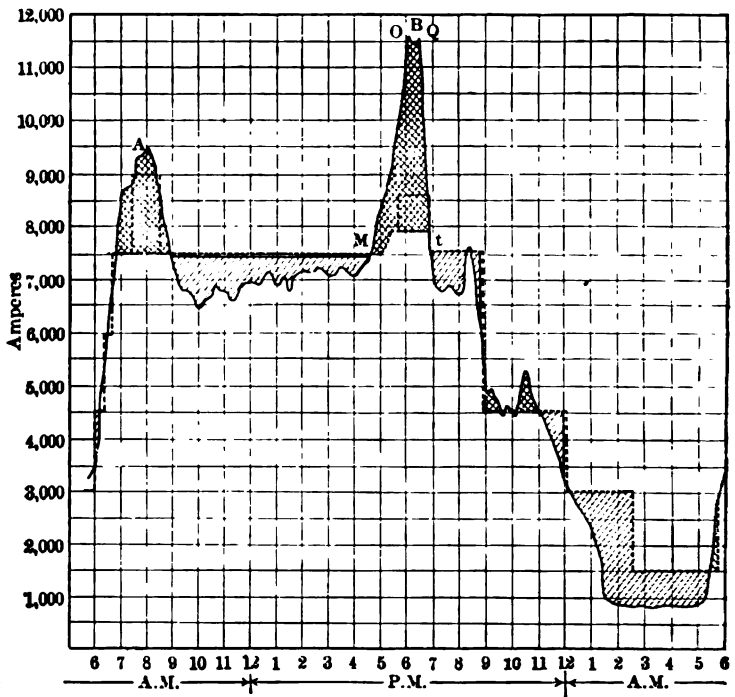


FIG. 164.

four hours. From this, the maximum, minimum and average current flow, the work required of the battery and the proper capacity for it, may all be determined with the help of the factors "K."

Take, as an example, the load diagram as shown in Fig. 164. The dotted line shows the generator output while the

heavy line shows the station output. The difference between the two at any instant is given out or absorbed by the battery. The diagonal shading shows charge and the cross hatching, discharge.

The peaks being some hours apart, may be considered as independent and having no bearing on each other, since the battery has sufficient time to fill up all that it has discharged on peak A before discharge on peak B begins. Therefore, the capacity of the battery will be that required to cover the greater peak which, by inspection, is seen to be peak B, and it only becomes necessary to determine the ampere hours which the battery must discharge to cover this peak, which is shown in enlarged section in Fig. 165, to better illustrate the method of computation. The diagram is

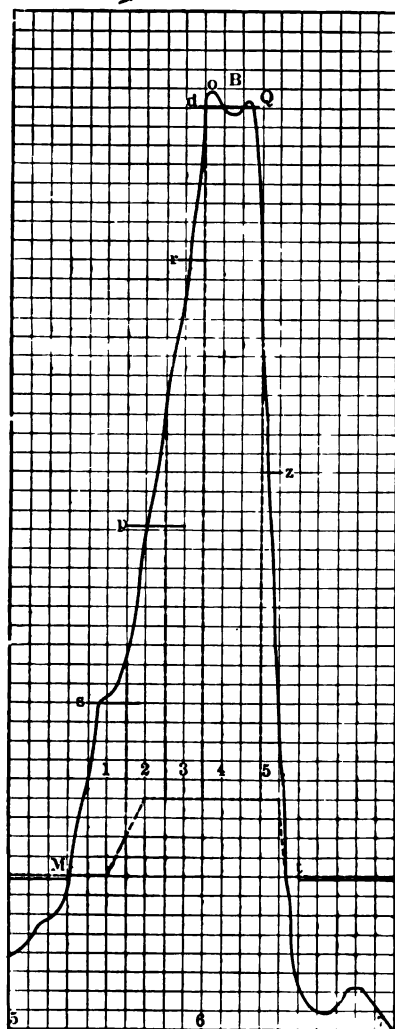


FIG. 165.

divided into a number of vertical laminæ by vertical lines. The area of each of these laminæ represents to proper scale

the ampere hours supplied to the outside circuit during the time covered by its base. The short horizontal lines s.p.r.d.z. represent the average discharge rates of the different divisions. The capacity required is now assumed to be, say 10 per cent. greater than the total ampere hours of the peak at the rate of discharge equal to the length of the peak base. The total ampere hours are 4,400 and time of discharge  $2\frac{1}{2}$  hours.  $K$  for  $2\frac{1}{2}$  hour rate is about 1.50.  $4400 \times 1.50 = 6600$  = approximate ampere hours required to carry the peak. Adopting this as the trial value, the use of the laminæ is resorted to for determining the final value.

Division No. 1 is 380 ampere hours at the 900 ampere rate = about the 7 hour rate. Therefore the battery capacity in ampere hours required for division No. 1 referred to the 8 hour rate, is  $380 \times 1.03 = 391.4$ . Similarly division No. 2 is 560 ampere hours at 1400 amperes, which is the  $3\frac{1}{2}$  hour rate with  $K = 1.25$  and ampere hours referred to 8 hour rate =  $560 \times 1.25 = 700$ . No. 3 = 1060, rate 2700 =  $1\frac{1}{2}$  hour rate.  $K = 1.68$ ; ampere hours =  $1060 \times 1.68 = 1780$ .

No. 4 = 2160 ampere hours, rate 3600, which is greater than the one hour rate. This would not be so objectionable if the time were only ten or fifteen minutes, but the base of this division is 36 minutes, which is too long to continue a discharge at such a high rate. Therefore, a new trial capacity must be adopted. Division No. 5 requires but little capacity. The sum of divisions 1, 2 and 3, as found, is 2871 referred to the 8 hour rate. If the one hour rate be taken as the highest allowable, then  $K = 2$  for division 4, and the ampere hours =  $2160 \times 2 = 4320$ . Adding to this the 2871 previously found, the result is 7181, or, say, 7200 ampere hours. The rates are now less for this than for the 6600 ampere hour battery and therefore the capacity should be great enough to also take care of No. 5.

Beginning again as before: Division No. 1 is 380 ampere hours, and as 900 amperes is the 8 hour rate,  $K = 1$  and the battery capacity for this division is 380 ampere hours.

No. 2 = 560 ampere hours at 1400 amperes =  $4\frac{1}{2}$  hour rate.  $K = 1.2$ , and ampere hours =  $560 \times 1.2 = 672$ .

No. 3 = 1060, rate 2700 =  $1\frac{2}{3}$  hour rate.  $K = 1.63$ , ampere hours =  $1.63 \times 1060 = 1730$ .

No. 4 = 2160, rate 3600 = 1 hour rate.  $K = 2$ ; ampere hours =  $2160 \times 2 = 4320$ .

No. 5 = 240, rate = 1700 =  $3\frac{1}{4}$  hour rate.  $K = 1.31$  ampere hours =  $240 \times 1.31 = 314$ . Total ampere hours = 7416. Therefore the assumed capacity of 7200 is also too small, and a 7400 ampere hour battery would be required. If this size be adopted, the total referred to the 8 hour rate will be

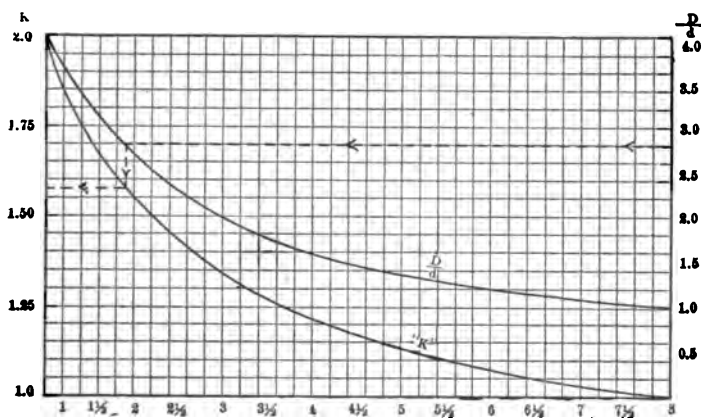


FIG. 166.

less than 7416, as the discharge rates will be less and the factors "K" correspondingly reduced.

To the capacity thus found, at least ten per cent. should be added to cover the loss of capacity which takes place after the battery has been some time in service, and toward the end of its life. For the case under consideration, this would make the proper capacity to install  $7400 + 740 = 8140$  ampere hours at the 8 hour rate.

As will be seen, this is a trial and error method, the accuracy of the result depending on the number of divisions into which a load curve may be divided.

In order to facilitate these calculations, the two curves shown in Fig. 166 have been prepared. The vertical scale

on the right refers to the upper curve, and the left vertical scale refers to the lower curve. "D" is any discharge in amperes, while "d" is the amperes discharge at the 8 hour rate.  $\frac{D}{d}$  is found and the value taken on the right-hand

vertical scale. Follow this horizontal thus located until it intersects the upper curve marked  $\frac{D}{d}$ . At the point of inter-

section, a vertical down to the horizontal scale will show the time rate of discharge at the amperes of flow = D. The vertical also intersects the lower curve marked "K." At this point of intersection, a horizontal to the left scale will give the value of "K" for the discharge rate D.

*Example:* What is the value of "K" for a discharge of 84 amperes from a battery having an 8 hour rate of 30 amperes?  $\frac{D}{d} = \frac{84}{30} = 2.8$ . Following the horizontal from 2.8

to curve  $\frac{D}{d}$  then vertically down to curve K, then horizontally to the left to scale "K" the value 1.56 is located. It may also be seen that 84 amperes discharge is the 1 hour and 57 minute rate of this battery. If  $\frac{D}{d}$  should exceed 4,

then the discharge is in excess of this 1 hour rate, and is too high except for a few moments. These curves are only approximations, as they vary somewhat with different types and makes of batteries, but they fairly represent average practice.

The data could be expressed in a single curve if the rate of discharge were omitted, and  $\frac{D}{d}$  placed on the horizontal scale in place of the time.

In computing battery capacity, it seldom is necessary to take into account the portion of the curve over which charge takes place, as in most plants there are short peaks and long hollows, and during the time the latter occur the battery fills up at a moderate rate.

There are some instances, however, where the charging

rate is necessarily high, and in such cases the minimum allowable size of the battery is that in which the  $1\frac{1}{2}$  hour

rate of charge is never exceeded. Rapid charge is much more injurious to a cell than rapid discharge, and in no case should current be passed into a cell at a rate higher than the  $1\frac{1}{2}$  hour rate, but even this is not good practice, and should not be allowed, if it is to last longer than twenty minutes, continuously.

Batteries used for regulation are subjected to high charging and discharging rates, though the time of either may be short. In such cases, the capacity required for storage is comparatively small; the maximum charge or discharge rate becomes the determining factor, and a battery installed large enough to absorb or give out these rates, without exceeding the  $1\frac{1}{2}$  hour rate of charge, or the 1 hour rate of dis-

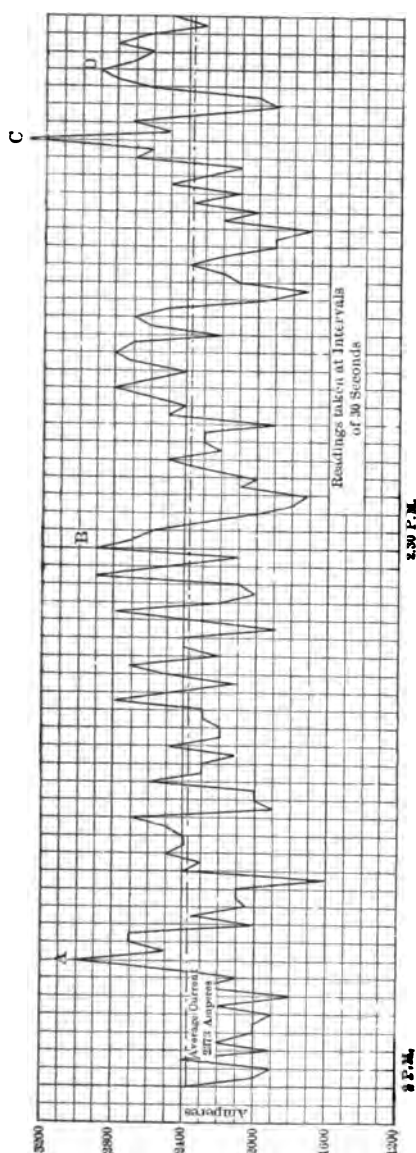


FIG. 167.



charge, regardless of the actual capacity required by the variations in load.

As an example, consider the load curve shown in Fig. 167 which shows station output for one hour from a rotary converter substation feeding on electric railway. The readings are taken at 30 second intervals.

In this case, the rotary converters are to supply the average current only, plus 10 per cent. on overloads and minus 10 per cent. on underloads. This average is 2373 amperes and on overload is  $2373 + 237 = 2610$  amperes and on underload  $= 2373 - 237 = 2136$  amperes.

The maximum load on the station is 3300 amperes, or 690 amperes more than the maximum output of the rotary. This difference is the maximum discharge rate of the battery. The minimum load is 1600 amperes or 536 amperes less than the rotary minimum is desired to be to maintain good regulation. This latter quantity, then, is the maximum charge rate of the battery.

The capacity required to cover the greatest peak is that for peak D, the actual ampere hours of which are just  $17\frac{1}{2}$ .

Taking 690 as the 1 hour rate of discharge, the capacity of the battery referred to the 8 hour rate ( $K=2$ ) is  $690 \times 2 = 1380$  ampere hours.

For a  $1\frac{1}{2}$  hour charging rate of 536 amperes ( $K=1.72$ ) the capacity of the battery should be  $536 \times 1.5 \times 1.72 = 1385$  ampere hours on the 8 hour basis.

When discharging over peak D, the average rate of discharge is about 375 amperes, which is the  $2\frac{1}{2}$  hour rate of a 1380 ampere hour cell, while the actual time of discharge is only  $3\frac{1}{2}$  minutes. So, if the maximum size, as determined by the requirements of charge and discharge rates, be adopted the battery will be many times greater than necessary, simply to supply current to the peak loads.

The battery, as here computed, will be unnecessarily large because the maxima of charge and discharge are sharp-pointed and are only instantaneous—lasting but a few seconds at most. If a horizontal be drawn across from the 2800 ampere mark on the left-hand vertical, it will cut but few of the peaks and the greatest duration of discharge

above this line is at peak D and lasts only 45 seconds. A battery, therefore, the 1 hour discharge rate of which rises up to the 2800 ampere mark, may be considered as sufficiently large for all practical purposes. The one hour discharge rate, then, is  $2800 = 2610 - 190$  amperes = 380 ampere hour battery at the 8 hour rate.

Similarly the difference between the 2136 amperes of the rotary converter and the 1900 ampere line, as a minimum station load, would seem well within the limits of good practice. This is 236 amperes and at the  $1\frac{1}{2}$  hour rate. Battery capacity is  $236 \times 1.5 \times 1.72 = 610$  ampere hours, referred to 8 hour rate.

From the foregoing, it is seen that the selection of size of battery is largely a matter of judgment and requires experience and a thorough knowledge of the subject in hand. These examples are given to indicate the methods by which the approximate size is determined, but the final settlement is based largely on judgment and previous experience.

Furthermore, the size of battery is greatly influenced by the character of the plant, prospects for increase, character of probable load increase. Also, the question of fuel and labor costs combined with the above considerations, may make a great difference.

## CHAPTER XLIV.

### LINE BATTERIES.

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Line batteries are those which are connected across the feeder system or line some distance away from the generator. The voltage of the line fluctuates with fluctuating load and, in many cases, the batteries simply "float," taking in current when the load is light and the line pressure high, and discharging when the load is heavy, assisting the generator and forming really a second source of current at a point where assistance is needed. In this way, the voltage may be maintained reasonably constant on long lines where the maximum currents would cause voltage drops too great for operation if the copper were not greatly increased or a battery installed. The battery also tends to maintain a constant load on the station so far as the particular feeder to which it is connected is concerned, and thus bring up the economy of station operation.

The "floating" battery, as stated, depends entirely on change in line drop for its operation. For instance, if the voltage of a system be 500 volts, the line resistance to battery .5 ohm, and the average load 60 amperes, the voltage at the battery will be  $500 - (.5 \times 60) = 470$  volts. If 470 volts be the E.M.F. of the battery, current neither discharges from it nor is charged into it when the average current is passing over the line.

If the load be decreased to say 20 amperes, the line drop is only 10 volts and the potential across the line at the battery is 490 volts which, being 20 volts above that of the battery, will cause a charging current to flow. Conversely an increasing load will increase the line drop and lower the voltage below that of the battery, resulting in battery discharge to assist the generator, the rate of discharge being

thus proportional to the load, and inversely proportional to the distance between the battery and the load.

A clearer understanding of this subject may be obtained from the following analytical discussion:

Let  $E_0$  = generator e.m.f.

$E_A$  = battery e.m.f.

$I_0$  = current from generator.

$I_x$  = current supply to load.

$r_1$  = total resistance of circuit exclusive of battery resistance.

$r_x$  = resistance of circuit up to point of application of load.

$r_1 - r_x$  = resistance from point of application of load to battery.

$R$  = resistance of battery (= virtual resistance.)

Call the average charging current  $I_{av}$  amperes when there is no load on the circuit. Then

$$E_0 - (I_{av} \times r_1) = E_A + (I_{av} \times R) \dots \dots \dots (61)$$

$$\text{or, } E_A = E_0 - I_{av} (r_1 + R) \dots \dots \dots (62)$$

Having determined  $E_A$  the number of cells in series is fixed and is equal to  $\frac{E_A}{2.05} = N$ .

The relation between  $I_x$  and  $I_0$  is established by the following equation:

$$E_0 - I_0 r_x - (I_0 - I_x) (r_1 - r_x) = E_A + R (I_0 - I_x) \dots \dots (63)$$

in which  $I_0 - I_x$  is the current from the generator to battery at any instant. When  $(I_0 - I_x)$  is negative (load greater than generator current) the battery is discharging.

Solving for  $I_0$  in eq. (63), this is found to be

$$I_0 = \frac{E_0 - E_A + I_x (R + r_1 - r_x)}{r_1 + R} \dots \dots \dots (64)$$

which shows the generator current under any conditions of load or battery voltage, when the generator is compounded to give a constant e.m.f.

If the generator be a shunt machine another factor must be included. Take, for instance, a shunt dynamo that gives 550 volts at no-load and 520 volts on full-load of 150 amperes.

The maximum voltage is  $E_{max} = 550$ . The voltage at any load  $= E_{max} - I_o h$ , in which  $h$  is a constant  $= \frac{E_{max} - E_{min}}{I_{max}}$

Equation 64 becomes

$$I_o = \frac{E_{max} - E_A + I_x (R + r_1 - r_x)}{r_1 + R + h} \dots \dots \dots (65)$$

This formula shows that with a shunt machine the gen-

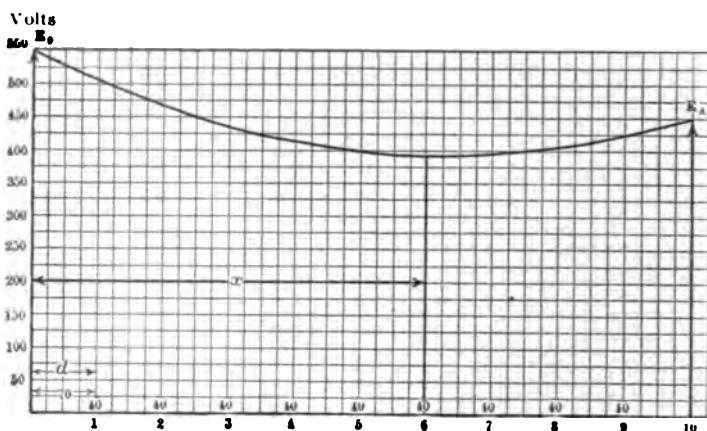


FIG. 168.

erator *current* variation is less than with a constant potential or compound machine, but that the voltage drop is greater at the point of application of the load.

These formulæ, however, cover only the simple case of a single load between the battery and the power station. In practice, there will be usually several cars or other translating devices, between these two sources of E.M.F., and the above formulæ no longer hold. In order to compute the drop and also capacity of battery, a general solution for a distributed load fed from two sources having different electro-motive forces, is necessary. The following should all be carefully

followed since it covers numbers of practical cases. It is also the *general case* of the division of load in a line fed from any two sources of E.M.F.

Referring to Fig. 168,  $E_0$  and  $E_A$  are the two sources of E.M.F. and  $V$  their difference. 1, 2, 3, 4, etc., are the points at which current is tapped off, and  $d$  is the distance apart of the taps. It is assumed that the taps are equi-distantly spaced, and that the current is the same through each tap.

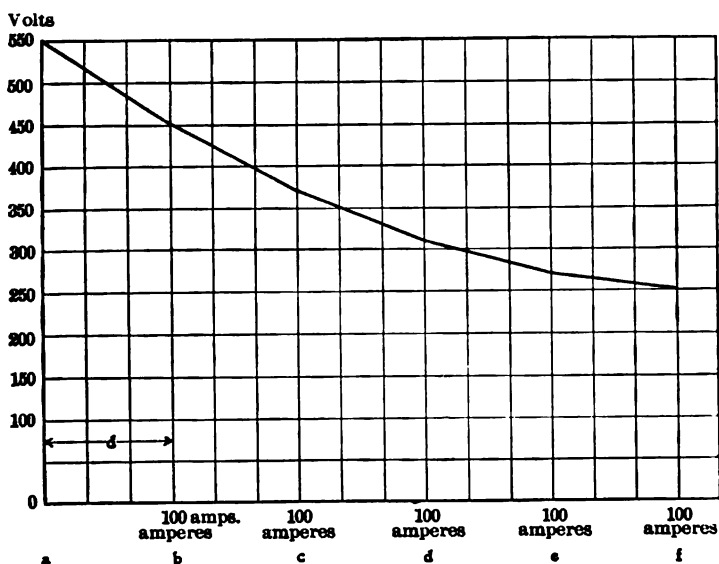


FIG. 169.

The current from the power station causes a drop along the line from  $E_0$  towards the right, while from  $E_A$  the voltage falls towards the left. There is some point at which the two opposing voltages will be equal and at this point no current will flow in the line in either direction, since the forces are in equilibrium.

All taps to the left of this point will be fed from  $E_0$  and all to the right by  $E_A$ . This condition exists at the point where  $E_0 - D_0 = E_A - D_A$  in which  $D_0$  and  $D_A$  are the drops from  $E_0$  and  $E_A$ , respectively.

The drop at any point in a line which is tapped at intervals

along its length, is equal to the sum of the currents flowing in the line at each tap point, multiplied by the resistance of the line from one tap to the next.

In Fig. 169, for example, if 100 amperes flow through each tap, and the resistance from one tap to the next be .2 ohm, the drop from a to b = the total amount of current flowing, multiplied by the resistance from a to b =  $500 \times .2 = 100$  volts. From b to c the drop is  $400 \times .2 = 80$  volts; from c to d =  $300 \times .2 = 60$ ; from d to e,  $200 \times .2 = 40$ ; and from e to f,  $100 \times .2 = 20$  volts. The drop from a to f is =  $100 + 80 + 60 + 40 + 20 = 300$  volts. Of course, this could be figured from e back to a in the same way, starting with 100 amperes  $\times .2$  as the first computation.

Referring now to Fig. 168, which represents a line fed from two sources, and calling  $x$  the distance from  $E_0$  to the point where  $E_0 - D_0 = E_A - D_A$ , we assume that this point will fall at a point on the line, which corresponds to the location of a tap. In this case, all the taps to the right will be supplied by  $E_A$  and all to the left by  $E_0$ , but the tap at which these potentials are equal will be supplied from both  $E_A$  and  $E_0$ , each furnishing one-half the amount taken.

Call  $a$  the amperes per tap, and  $r$  the resistance of the line between taps. If, now, for instance, the point  $x$  should fall on tap 7, the drop at 7 from  $E_0$  would be  $\frac{1}{2} ar + \frac{3}{2} ar + \frac{5}{2} ar$  etc., up to  $\frac{13ar}{2}$ , the last term being the number 13, which, in this case is  $7 - \frac{1}{2} = \frac{x}{d} - \frac{1}{2}$ ,  $\frac{x}{d}$  being the number of taps in the length  $x$ .

The formula for  $D_0$  = drop from  $E_0$  to  $x$ , then becomes

$$D_0 = ar \left\{ \frac{1}{2} + \frac{3}{2} + \frac{5}{2} + \dots + \left( \frac{x}{d} - \frac{1}{2} \right) \right\} \frac{x}{d} \quad (66)$$

The quantity in the brackets is an arithmetical progression in which the first term is  $\frac{1}{2}$  and the last term  $\frac{x}{d} - \frac{1}{2}$ , and its sum is

$$\frac{\frac{1}{2} + \left( \frac{x}{d} - \frac{1}{2} \right) \frac{x}{d}}{2} \dots \dots \dots (67)$$

that is, one-half the sum of the first and last terms, multiplied by the number of terms.

$$D_0 = \frac{ar \left( \frac{x}{d} \right)^2}{2} \dots \dots \dots (68)$$

Calling  $L$  the distance between  $E_0$  and  $E_A$ , the latter supplies current to that portion of the line which is represented by  $L - x$ .

In the same way as the foregoing the drop  $D_A$  from  $E_A$  to the point  $L - x$  may be shown to be

$$\frac{1}{2} ar \left( \frac{L - x}{d} \right)^2 \dots \dots \dots (69)$$

in which  $D_0 = D_A + V$ .

$$\therefore \frac{1}{2} ar \left( \frac{x}{d} \right)^2 = \frac{1}{2} ar \left( \frac{L - x}{d} \right)^2 + V \dots \dots \dots (70)$$

$$\frac{x^2}{d^2} = \left( \frac{L - x}{d} \right)^2 + \frac{2V}{ar}$$

$$x^2 = (L - x)^2 + \frac{2Vd^2}{ar}$$

$$2Lx = L^2 + \frac{2Vd^2}{ar}$$

$$x = \frac{1}{2} \left\{ L + \frac{2Vd^2}{arL} \right\}$$

$$= \frac{L}{2} + \frac{Vd^2}{arL} \dots \dots \dots (71)$$

That is, the distance of the point to where  $E_0$  will feed, is one-half the distance between the sources of E.M.F. plus a fraction which depends for its value on the difference between  $E_0$  and  $E_A$ , on the distance apart of the taps, on the current per tap, the resistance from tap to tap and the total length from  $E_0$  to  $E_A$ .



As an example, assume the following:

$$E_o = 550 \text{ volts.}$$

$$E_A = 450 \text{ volts.}$$

$$L = 40,000 \text{ feet.}$$

$$d = 4,000 \text{ feet.}$$

$$a = 40 \text{ amperes.}$$

$$\text{resistance of circuit} = .05 \text{ ohms per 1,000 feet.}$$

$$\therefore r = \frac{4,000 \times .05}{1,000} = .2 \text{ ohms.}$$

$$V = 550 - 450 = 100.$$

$$x = \frac{40,000}{2} + \frac{100 \times (4,000)^2}{.2 \times 40 \times 40,000} = 25,000 \text{ feet from } E_o,$$

and 15,000 feet from  $E_A$ .

This point does not fall on a tap, but passes tap 6 and lies 1,000 feet beyond and 3,000 feet from tap No. 7. From the conditions of flow it is clearly impossible, for the actual point of equal voltage to come between two taps, as this would mean either that two currents flowed at the same time in opposite directions, or that electrical energy accumulated at some point in the wire.

In the case under discussion, the position computed simply means that  $E_A$  furnishes a portion of the current to tap No. 6, that is, the tap nearest the computed  $x$  is fed from both sources, and the current supplied by each is inversely proportional to the distance from  $x$  to tap 6, as related to the distance from tap 6 to tap 7.

The distance between 6 and 7 is 4,000 feet and from  $x$  to 6 is 1,000 feet. Therefore, of the 40 amperes furnished to tap 6, one-fourth, or 10 amperes, is supplied by  $E_A$  and 30 amperes from  $E_o$ . Computation of drop shows that with this distribution  $D_o = D_A + V$ . It is obvious that the drops are less after transferral than the computed, since only a small amount of current flows over the line between 6 and 7.

When the point  $x$  falls on a tap, half of the current to the tap is supplied by each of the sources. When  $x$  falls half-way between two taps, it means that no current passes over the line connecting these two taps, and the voltage distribution would be the same if the line between them were cut in two. If, for instance,  $x$  should fall half-way between 6 and

7, all current to the first six taps would come from  $E_0$ , while all to 7, 8 and 9 would be furnished by  $E_A$ , and the potential at 6 would be equal to the potential at 7. The drops would also be smaller than the computed, as no drop would be caused by the resistance from 6 to 7, since no current flows over this part of the line.

The current supply from each source can now be determined.

From  $E_0 = 40 \times 5 + 30 = 230$  and

From  $E_A = 40 \times 3 + 10 = 130$

The total current supplied  $= 360$  or  $= 9 \times 40$ .

The voltage of the battery when neither charging nor discharging—2.05 volts per cell—must be equal to the drop from  $E_0$  at average load. The voltage of the battery on discharge is less than this amount by the drop due to the virtual internal resistance, and in railway work, where the changes are very quick, may be taken as .2 volts per cell.

$E_A$  is usually taken as  $2.05 - .2 = 1.85$  volts per cell, it being assumed that the battery keeps nearly full and is discharged at the one hour rate on maximum load.

The foregoing is based on the assumption that the road is level and all cars or other translating devices are using equal amounts of current, and also that they are equally distributed over the line. Where there are grades, or the distribution is unequal from any cause, there can be no general formula, since  $a$  and  $r$  vary with each case, and no series can be formed. In such cases, the method of locating  $x$  is by trial.

Assume  $x$ , and compute the drop from  $E_0$  and to  $E_A$ , thus located. If  $D_0 = D_A + V$  the point is properly located.

If  $D_0 > D_A + V$  then  $x$  has been assumed too great, and another trial calculation must be made. If  $D_0 < D_A + V$ ,  $x$  must be increased.

As an example, assume a line with the conditions as shown in Fig. 170,  $E_0 = 550$ ;  $E_A = 450$  and  $V = 100$ .

$C_1$ ,  $C_2$ ,  $C_3$ , etc., are cars; their direction of motion being indicated by the arrows. The amperes taken and distance apart of taps are indicated.

Resistance per 1,000 feet  $= .2$  ohm.

Assume  $x$  to fall between  $C_4$  and  $C_5$ . Then the drop from  $E_0$  will be as follows:

$$.2 [(20+40+20) 5 + (40+20) 3 + (20) 7] = 144 \text{ volts.}$$

The multipliers 5, 3, 7 outside the parentheses are the number of thousands of feet between the cars.

In the same way the drop from  $E_A = .2 [(10+40+35) 4 + (40+35) 3 + (35) 5] = 148 \text{ volts.}$

Since  $D_A < D_0 + V$ ,  $x$  has been taken too small. Assume it now at the point  $x_2$  between  $C_5$  and  $C_6$ .  $D_0 = 340 \text{ volts.}$

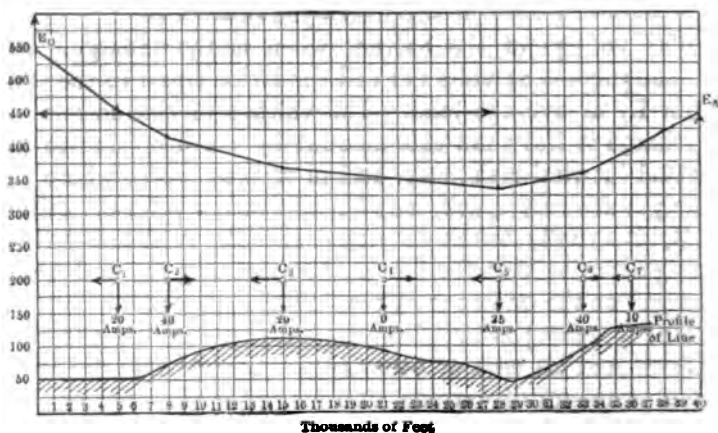


FIG. 170.

$D_A + V = 164$ , therefore  $x$  is much too great. It therefore must fall on tap  $C_5$ ,  $E_0$  and  $E_A$  each supplying a portion of the current at that tap. Assume that 20 amperes are supplied by  $E_A$  and 15 by  $E_0$ ; then the drop from  $E_0$  to  $x = 228 \text{ volts}$ , and  $D_0 + V = 212$ . This means that  $E_A$  should furnish a greater and  $E_0$  a less amount of current to  $C_5$  than the assumed quantities.

The line resistance from  $E_0$  to  $x = (5+3+7+6+7) .2 = 5.6 \text{ ohms}$ , and from  $E_A$  to  $x = (4+3+5) .2 = 2.4 \text{ ohms}$ .

Therefore, for each ampere more furnished from  $E_A$  there is an increase in  $D_A$  of 2.4 volts, and a decrease in  $D_0$  of 5.6 volts, or a change of 8 volts per increase of 1 ampere from  $E_A$ .

$$\frac{228 - 212}{8} = \frac{16}{8} = 2;$$

which makes the amperes from  $E_0$  to  $C_s = 13$  and 22 from  $E_A$ .

Re-computation of the drop shows that the fall is 216.8 from  $E_0$  and 116.8 from  $E_A$ , making  $D_0 = D_A + V$ .

The practical question which usually arises in the case of a feeder or line on which the voltage drop is too great and it is desired to determine the location of the battery, its voltage and capacity. Referring to Fig. 171,  $L$  is the total length of the line,  $Y$  is the distance of the battery from the

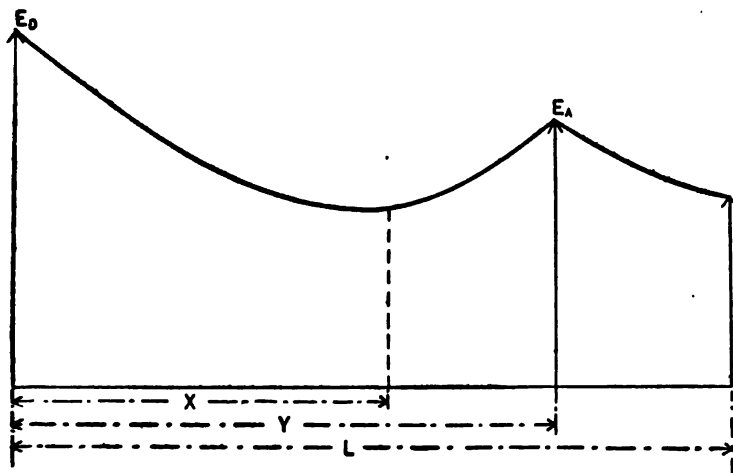


FIG. 171.

station,  $E_A$  is its voltage, and  $X$  is the point at which  $D_0 = D_A + V$ , as before.

It is obvious that if the resistance of the line be constant, and a minimum voltage over the line is specified, the battery will feed to an equal distance in either direction, and

$$Y - X = L - Y \dots \dots \dots (72)$$

The minimum drop on the line is specified and is equal to the drop at  $X$ , which we call  $D_0$ .

From equation (68)  $D_0 = \frac{1}{2} \text{ ar } \left( \frac{X}{d} \right)^2$

$$\therefore X = d \sqrt{\frac{2D_0}{ar}} \dots \dots \dots (73)$$

which locates X.

From the equation (72)

$$Y = \frac{L + X}{2} \dots \dots \dots (74)$$

which locates Y.

From the condition that voltage of the generator minus the drop to X must equal the battery voltage minus its drop to X, we have

$$E_0 - D_0 = E_A - D_A \quad \therefore E_A = E_0 - D_0 + D_A \dots \dots \dots (75)$$

$$D_A = \left( \frac{(Y - X)a + a}{2d} \right) \times \left( \frac{Y - X}{d} \right) r \dots \dots \dots (76)$$

$$= \frac{ar}{2} \left( \frac{Y - X}{d} \right)^2 + \left( \frac{Y - X}{d} \right) \dots \dots \dots (77)$$

whence

$$E_A = E_0 - D_0 + \frac{ar}{2} \left( \frac{Y - X}{d} \right)^2 + \left( \frac{Y - X}{d} \right) \dots \dots \dots (78)$$

As a practical example: assume a railway 50,000 feet long, and distance apart of cars = 5,000 feet =  $d$ . There will be 10 taps on the line. Assume that each takes 30 amperes. Total current = 300 amperes.

Minimum voltage at any point on the line = 350 volts.

$D_0 = 550 - 350 = 200$  volts.

Resistance of line = 4 ohms.

$$\therefore r = \frac{4 \times 5,000}{50,000} = .4 \text{ ohms for distance } = d.$$

$$X = 5,000 \times \sqrt{\frac{2 \times 200}{30 \times .4}} = 28,810 \text{ feet.}$$

$$Y = \frac{50,000 + 28,810}{2} = 39,405 \text{ feet.}$$

$$D_0 = \frac{30 \times .4}{2} \left\{ \left( \frac{39,405 - 28,810}{5,000} \right)^2 + \left( \frac{39,405 - 28,810}{5,000} \right) \right\}$$

$$D_0 = \frac{12}{2} \left\{ \left( \frac{10,595}{5,000} \right)^2 + \left( \frac{10,595}{5,000} \right) \right\} = 39.4$$

$$\therefore E_A = 350 + 39.4 = 389.4$$

The generator supplies  $\frac{28,810}{5,000} \times 30 = 173$  amperes, while the battery supplies  $(10 \times 30) - 173 = 127$  amperes. Calling

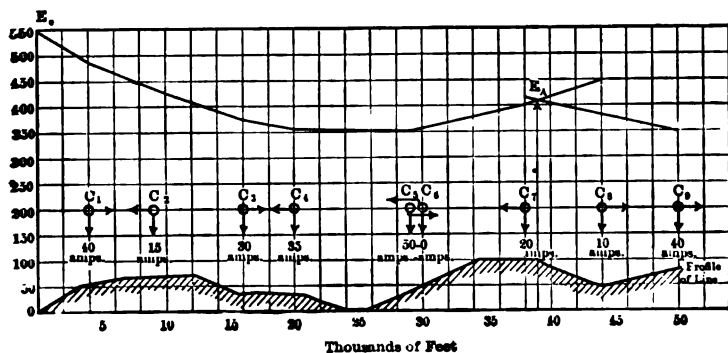


FIG. 172.

this the one hour rate, the capacity of the battery should be  $127 \times 2 = 254$  ampere hours.

If the exact solution of this problem is desired, it will be necessary to transfer X from the point 28,810 feet, which falls 3,810 feet beyond the fifth tap and within 1,190 feet of the sixth, to the sixth tap by the method previously given.

This transfer will change the location of Y, which should, when possible, be placed at a tap point, or in case of moving cars, placed in such a position as to be near or at the point passed by a car when maximum current is drawn from the line.

As a practical example of location on a line with grades and proper voltage and capacity of a battery, the conditions shown in Fig. 172 may be assumed.

$E_0 = 550$ ,  $r$  per 1,000 feet = .125 ohms. Maximum voltage drop = 200 volts.

From inspection assume  $X$  to be at  $C_5$  and that one-half the current to  $C_5$  is delivered from each source.

The drop from  $E_0$  to  $C_5$ , however, is 275 volts, which is greater than the permissible. Now assume  $E_0$  to feed up to  $C_4$  and supply all the current thereto. The drop to  $C_5$  is found to be 183.4 volts. This is 16.6 volts less than the permissible drop, and some current will be furnished to  $C_5$  by  $E_0$ , the amount being equal to

$$\frac{16.6}{.125 \times 29} = 4.6 \text{ amperes.}$$

29 being the thousands of feet from  $E_0$  to  $X$ .

Starting from  $C_5$  at the voltage 350 ( $= 550 - 200$ ), and working towards the right the curve of drop towards  $Y$  is plotted, it being remembered that current to  $C_5$  from  $E_A$  is  $50 - 4.6 = 45.4$  amperes; and beginning at  $C_0$  and working towards the left, the curve of drop to  $Y$  is plotted. The intersection of these curves locates  $Y$  and gives the value of  $E_A$ .

In this case, the intersection falls at point 10,100 feet from  $C_5$  and 10,900 feet from  $C_0$ , and the voltage  $E_A$  is 420 volts. This corresponds to 227 cells at a minimum voltage of 1.85. The floating voltage is  $227 \times 2.05 = 465$  volts. If this is greater than the average voltage of the line at the point where the battery is located, a booster must be installed, which will take up the loss in battery voltage on discharge. If a booster were installed, the number of cells required

would be  $\frac{420}{2.05} = 205$  cells.

The total output of the line = 240 amperes, of which the generator furnishes 124.6. The battery, therefore, must supply  $240 - 124.6$ , or 115.4 amperes. If this be the one hour discharge rate, the size of the battery will be  $115 \times 2 = 230$  ampere hours, rated on the 8 hour basis.

In some cases, the discharge from the battery will be greater or less than the amount of charge it receives from the line, depending on whether  $E_A$  is above or below the

voltage of the line at the battery on average load. If less, the number of cells should be increased to bring  $E_A$  up to the average voltage. If greater, the only help is a constant current booster, or more feeder copper, or both. If it is not objectionable to raise the voltage of the feeder, the booster may be put in series with it, the added voltage being just enough to make the line voltage at the battery equal to  $E_A$  on average load, and the carrying capacity of the booster must be equal to the average line load. In some cases it may be necessary to run an auxiliary feeder to the battery, the constant current booster being in series with it. The carrying capacity of the feeder and booster must be such as to deliver continuously a current equal to the *average* difference between the amount of current put into the battery by the line, and its discharge.

The voltage must be just sufficient to cause this amount of current to flow through the auxiliary feeder into the battery on average load. If it is higher, the line will be partly fed from the auxiliary feeder and the battery will not do its share of the work, and the  $C^2R$  loss in the feeder will be increased owing to the increase in current through it.

Consider now the question of difference in cost between the battery and a sufficient amount of copper to effect the same result, and take, as a concrete example, the case shown in Fig. 172. Take the track resistance as equal to .015 ohms per 1,000 feet. The resistance total per 1,000 feet is .125, making the feeder resistance .11 ohms per 1,000 feet, corresponding to about a No. 6 hard drawn copper wire with splices. While this is somewhat small for the maximum current carried, it does not affect the result as to increased copper required to maintain the voltage. It is also quite large enough for the current it carries with a battery on the line, since the greatest current is that from  $E_0$  to  $C_6$ , which at maximum load is 124.6 amperes.

The drop computed on a basis of .125 ohms per 1,000 feet is 767 volts at the end of the line, or far more than the generator voltage. If the drop is to be 200 volts, the resistance of the line must be equal to  $\frac{200 \times .125}{767} = .03265$  ohms.



The resistance of the track being .015, the copper resistance must be  $.03265 - .015 = .01765$  ohms per 1,000 feet, which corresponds to about 610,000 circular mils. The cross section of the trolley wire in place is 105,500 circular mils.

The additional copper required, then, is  $610,000 - 105,500 = 504,500$ , say 500,000 circular mils. Taking the cost of copper erected as 18 cents per pound, including additional cross arms, insulators, labor, etc., the cost of this copper would be about \$14,200.

The cost of the battery would be as follows:

227 cells of 230 ampere hour capacity at \$19.00 ..	\$4,313.00
Switchboard.....	220.00
Erection.....	380.00
	<hr/>
	\$4,913.00

The large feeder would reduce the C<sup>2</sup>R loss below that of the smaller one—which latter is sufficiently large if the battery be installed, but the economy effected by the latter in steadying the load on the power station will much more than counterbalance this saving in C<sup>2</sup>R loss.

If the battery be installed with a booster, the voltage of the latter need be only great enough to regulate, or  $.2 \times 227 = 45.4$  volts, since the battery voltage is below that of the generator and overcharging can be done at times of light load and high line voltage, the booster assisting the line. The current carrying capacity would be, say, 70 per cent. of 115 amperes, or 80.5 amperes, making the booster capacity  $80.5 \times 45 = 3.63$ , say 4 K.W. The size of the motor =  $\frac{3.63 \times 134}{.80\% \text{ eff'y}} = 6$  H.P. The cost of the motor and booster installed would be about \$340, but 21 cells less of battery would be required, and their value is \$399, so that the plant would really cost \$59 less with the booster than if installed without it.

The floating battery has the advantage of simplicity, and acts instantaneously, as it has no time lag, which is always

present in a booster as the latter depends on changes in its magnetization to effect changes in e.m.f. The variation in voltage required and the fluctuation in generator load are, however, too great to admit of successful operation on any but a railway or power circuit, and generally a proper booster would help the regulation greatly.

## CHAPTER XLV.

### PLANT EFFICIENCY.

---

The efficiency of batteries on storage and regulation service have been previously treated in Part I, Chapter XI. The addition of boosters, of course, lowers the efficiency somewhat, but not so much as might be at first supposed.

Consider first a case of regulation on a system with a fluctuating load, such as is shown in Fig. 173.

The average load to be furnished by the generator is 605 amperes and is indicated by the horizontal dotted line. The readings are taken at intervals of five seconds. The battery is to absorb all the excess current when the external load falls below the 605 amperes line, and deliver all current required above this amount.

The maximum excess is 300 and maximum deficiency 200 amperes. Since, however, these maxima never last over five seconds, the hour discharge rate of the battery may be taken as 260 amperes. The factor K for the one hour rate = 2 and the capacity of battery required at the 8 hour rating is  $2 \times 260 = 520$  ampere hours. The booster must be large enough to stand the momentary overloads up to 300 amperes. On fluctuations of this kind a good machine can

work on overloads of 75 per cent. at least.  $\frac{300}{1.75} = 171 =$   
ampere capacity of booster if operated continuously.

The battery being for regulation only, the number of cells  $= \frac{V}{2.05}$ , it being assumed that a booster in series with the battery will be used, the voltage of which is zero at normal load. In this case, the voltage of the system is 220 and the number of cells, therefore,  $\frac{220}{2.05} = 107$ . The maximum volt-

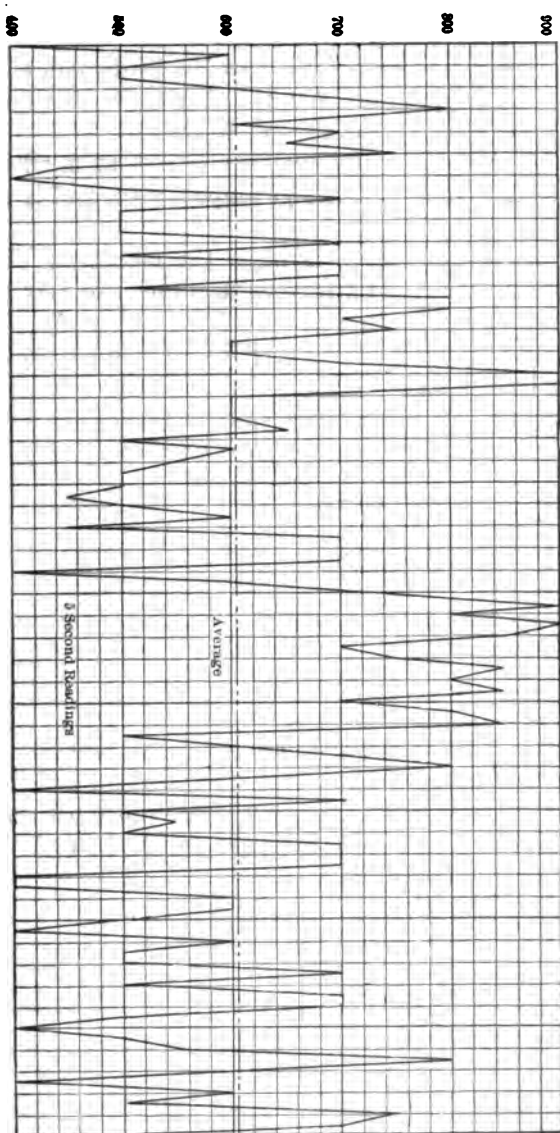


FIG. 173.

age of this battery, when being overcharged, is  $107 \times 2.6 = 278$  volts, of which 58 volts must be furnished by the booster. Therefore  $58 \times 171 = 9.92 =$  booster K.W. For good regulation, however, the voltage due to the shunt coil should be not less than 75 volts. On this basis, the booster K.W. would be  $171 \times 75 = 12.8$ , say, 13 K.W.

The maximum, continuous booster output is when overcharging the battery at the 75 ampere rate, and is equal to  $75 \times 58 = 4.35$  K.W.

The maximum output is when the maximum discharge takes place, with the battery voltage down to 1.75 per cell. The motor input under these conditions must be equal to  $(220 - 107 \times 1.75) \times 300 = 9.75$  K.W. with proper addition to cover booster losses.

The motor can work at the same overload capacity for a few seconds as the booster, therefore the capacity may be taken as  $\frac{9.75}{1.75} = 5.57$  K.W., not considering losses. Assume

the efficiency of the booster to be 80 per cent., of which 4 per cent. is the constant loss of friction, windage, etc., 4 per cent. shunt field loss, 8 per cent. iron, and 4 per cent. copper loss. This gives 8 per cent. constant losses and 12 per cent

varying with the load. The size of the motor is  $\frac{5.57}{.80\%} = 7.2$ , say 7 K.W. Assume the motor efficiency as 80 per cent., the 20 per cent. loss being 3 per cent. friction and windage, 4 per cent. shunt field, 8 per cent. iron, and 5 per cent. C<sup>2</sup>R loss. Of these the first three are constant, and the last varies with the load.

The constant losses, then, are

$$(7 \times .15) + (13 \times .08) = 2.09 \text{ K.W.}$$

From the curve it may be found that the *average* booster discharge throughout the time covered is 22 amperes. The

average copper loss then is  $\frac{(22)^2}{(170)^2} \times .04 \times 13 = .01345$  K.W. =

13.4 watts, which is negligible. The iron loss is also negligible because of the very low average voltage of the booster. This roughly may be computed as follows:

The 8 hour rate of the battery = 65 amperes and drop per

cell = .062. Then volts  $\frac{.062 \times 107 \times 22}{65} = 2.25$  volts, which is

the average voltage of the booster.

It also follows that the armature copper losses in the motor on regulation are inappreciable.

The amount of energy put into the battery is 22,000 ampere seconds =  $22,000 \times 222.3 = 4,890$  K.W. seconds.

Assuming the battery efficiency to be 92 per cent., the loss is  $.08 \times 4,890 = 391.2$  K.W. seconds.

Summing up the losses for the 1,000 seconds covered by the curve, we have  $2.09 \times 1,000 = 2,090$  K.W. seconds loss in motor and booster.

Allow copper losses.....	44	K.W. seconds.
Battery loss.....	391	" "
Total.....	2,525	" "

The total energy delivered is 4,890 K.W. seconds, and, therefore, the total energy taken from the line was 4,890

+ 2,525 = 7,415 K.W. seconds.  $\frac{4,890}{7,415} = 66\% = \text{efficiency of}$

battery equipment. This figure, however, gives no conception of the effect on the station which, after all, is the *crux* of the discussion.

The total output of the plant during the period covered by the curve was 605,000 ampere seconds, or  $605,000 \times 220 = 133,100$  K.W. seconds. The losses were 2,525 K.W. seconds and total energy generated was  $133,100 + 2,525 = 135,625$  K.W. seconds.  $\frac{133,100}{135,625} = 98.5$  per cent. plant efficiency. For

a loss of  $1\frac{1}{2}$  per cent. of the total energy generated, fluctuations, which vary as much as 50 per cent. of the average output, have been taken off the engines and dynamos with a consequent saving of from 10 to 20 per cent. in fuel consumption. The battery, motor and booster losses are therefore negligible as compared with the total load steadied and the saving resulting therefrom. The difference in steam, consumption of engines, working at a steady rate and

on fluctuating loads, has been shown in numerous tests and experiments. One of the most striking is a test conducted by N. S. Hill, Jr., on a 250 H.P. direct connected high speed unit. The engine was simple, non-condensing. Fuel consumption on steady, normal load was 3.5 lbs. coal per H.P. hour. On fluctuating load, the mean of which was near the normal rating of the engine, and the rapid variations running from 50 per cent. under to 50 per cent. overload, the consumption increased to 7.25 lbs. per H.P. hour; an increase of nearly 100 per cent.

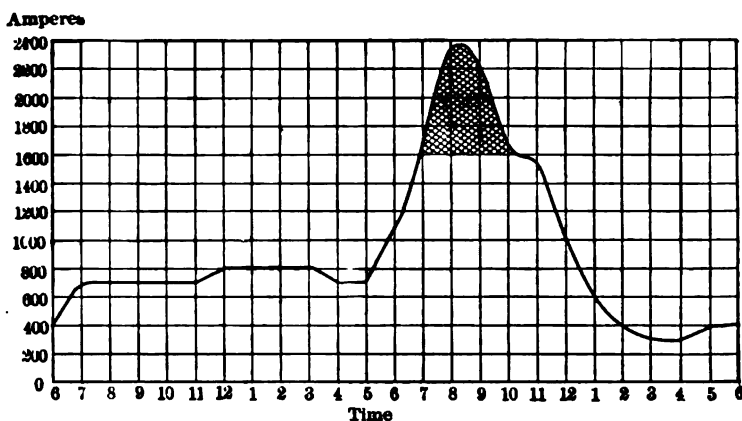


FIG. 174.

In the case of applications to carry load peaks, the computations do not show so marked an advantage, and indeed there are many cases where it is more economical to carry the peaks with generating machinery if the sole office of the battery is to handle these excess loads, and the features of reliability, equalizing, maintenance of constant bus bar voltage and the other advantages which go to make a battery of value in a station, be neglected.

Consider a plant working on 110 volts, having a load curve such as that shown in Fig. 174 and equipped with generating machinery to carry 1,600 amperes. The peak rising above 1,600 and shown by the cross hatched area and representing 1,530 ampere hours, is to be carried by a battery.

From the charge and discharge curves shown in Fig. 175, which are for the 5 hour rate of charge and 2 hour rate of discharge, it is found that the average voltage of charge is 2.29 and that of discharge 1.93 for the particular cell from which the curves are taken.

The ampere hour efficiency may be taken as about 90 per cent. Then  $\frac{1530}{90} = 1700$  = ampere hours of charge. The voltage added to this charge by the booster is 61 (2.29 - 1.93) = 22 volts.

$22 \times 1700 = 59.4$  K.W. hours added by booster.

Assuming the motor and booster efficiencies as 88 per cent.

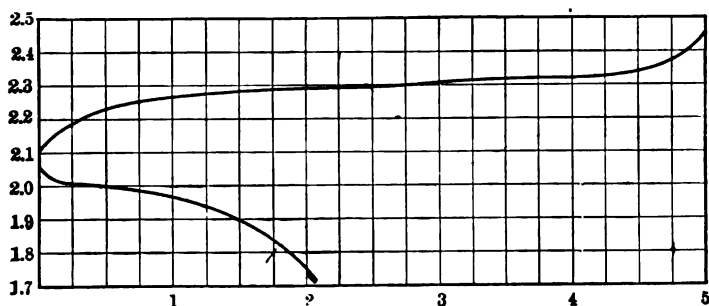


FIG. 175.

each for machines as large as these, the combined efficiency is 77.5 per cent. The energy taken from the switchboard therefore by the booster motor is

$$\frac{59.4}{.775} = 76.5 \text{ K.W. hours.}$$

The total energy taken from the switchboard, then, is  $76.5 + 1700 \times 110 = 263.5$  K.W. hours.

The battery puts back into the line

$$1530 \times 1.93 \times 61 = 180 \text{ K.W. hours,}$$

and the loss is 83.5 K.W. hours.

The efficiency of the system then is  $\frac{180}{263.5} = 68.3$  per cent. = efficiency of the battery equipment.

The total station output is 22.430 ampere hours, which, at 110 volts = 2467 K.W. hours.



The total energy generated is  $2467 + 83.5 = 2550.5$  K.W. hours.

Efficiency of plant  $= \frac{2467}{2550.5} = 96.8$  per cent. Loss = 3.2 per cent. of total daily output.

Assume the efficiency of the engine and generator to be 90 per cent. each. The combined efficiency = 81 per cent.

Then 180 K.W. hours at the switchboard  $= \frac{180 \times 1.34}{80} = 298$

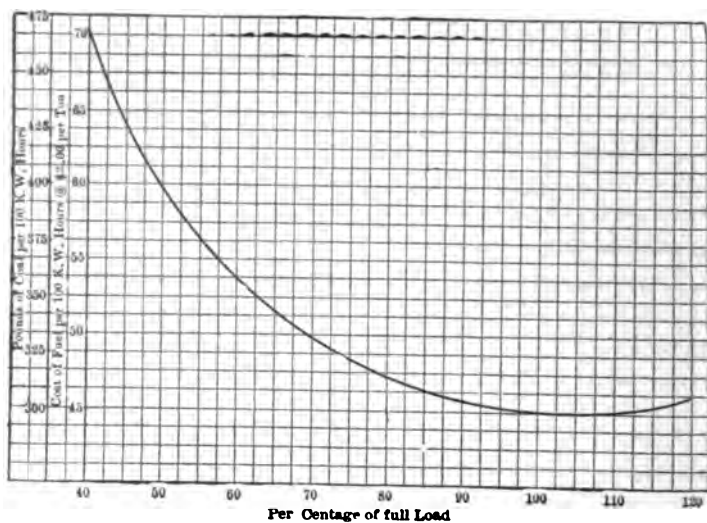


FIG. 176.

cylinder or I.H.P. required and the 263.5 K.W. used in charging the battery = 435 I.H.P.  $\frac{435}{298} = 1.46$ . Therefore, for each I.H.P. which the battery discharges on the peak, 1.46 I.H.P. must be developed, in the engine cylinder, or nearly 50 per cent. excess.

As to whether this increased power can be produced at a less cost at certain periods of load than the amount discharged into the line can be at the time of heavy loads, depends on the type of station, its steam and generating equipment, and the character of the load.

Referring to curve, Fig. 176, it is seen that the fuel consumption per H.P. hour increases rapidly as the load decreases. This curve is not applicable to any general case, but varies for each particular station. If the unit be of 250 K.W. normal capacity and is working at the 100 K.W. rate, it is costing 70 cents per hour for fuel at this 40 per cent. load. If 146 H.P. be added on to the generator load to charge the battery, the total load  $100 + 146 = 246$  H.P., or practically full load cost of fuel per hour  $= 246 \times 45 = \$1.10$ . The additional fuel cost to charge the battery then is  $\$1.10 - 70 = 40$ . The battery will give out 100 K.W. hours for the 146 charged into it. If, at the time of the peak, the whole plant were to run on full load, it would cost 45 cents to generate the 100 K.W. hours. This shows a saving of 5 cents, or 11 per cent. in fuel by using the battery to carry the peak of the load. If the plant were not running on full load the saving would be still greater. Also if the boiler capacity of the plant is smaller than it should be for handling the peak, the saving in favor of the battery will still further be increased.

On the other hand, if at light load the units at work are delivering an output near their full load capacity and to charge the battery another unit would have to be started up which would not be fully loaded by the battery, and the generating and steam equipment properly proportioned to handle the peaks, then the installation of a battery for the sole purpose of handling the heavy load would result in a positive loss.

It therefore depends entirely on the character of the station and its equipment, whether or not a battery is the most economical apparatus to take care of a steady overload.

In most stations, however, the regulating effect and guarantee against breakdowns are the chief factors which influence the installation of a battery plant.

## CHAPTER XLVI.

### EXAMPLE OF APPLICATION OF A BATTERY TO AN ISOLATED PLANT.

---

Conditions: Isolated plant in hotel or apartment house. Battery to regulate on the elevator load and also carry the night load, the generating machinery being shut down. 110 volt system. Three elevators, 75 amperes starting and 35 amperes running current. Maximum current to elevators  $= 75 + 75 + 35 = 185$  amperes; that is, the starting of two elevators simultaneously while one is running, will probably often occur. The average current to elevators for the 24 hours, is 40 amperes. This quantity may be approximated by assuming a given number of trips of each elevator per diem, with the time and current consumption, allowing from three to four seconds at the starting rate. A wattmeter in the circuit, or an ampere meter is the best way, however, to fix on the average if the plant is already installed. If not, the above assumption must be made, and a working figure arrived at.

Assume further, that the load curve of the plant is as shown in Fig. 177, and the period of shut down is to be from 1 A. M. to 1 P. M., the following day, as indicated by the cross hatched area which represents battery discharge. This area shows a battery capacity of 840 ampere hours.

The battery capacity required for regulation only is  $185 - 40 = 145$  amperes at the one hour rate, which is equal to 290 ampere hours referred to the 8 hour rate. Therefore, the capacity required for storage is 550 ampere hours in excess of that required for regulation.

The maximum amperes passing through the booster into the battery are 40 for the elevator load, and 170 for the charging, making 210. The armature of a constant current

booster would have to be large enough to take this current for at least two hours continuously.

If the booster were a machine in series with the battery, its armature would have to carry  $170 + 145 = 315$  amperes, and it would therefore be a much larger machine than the constant current booster.

Number of cells required =  $\frac{110}{1.8} = 61$ . Since the battery will

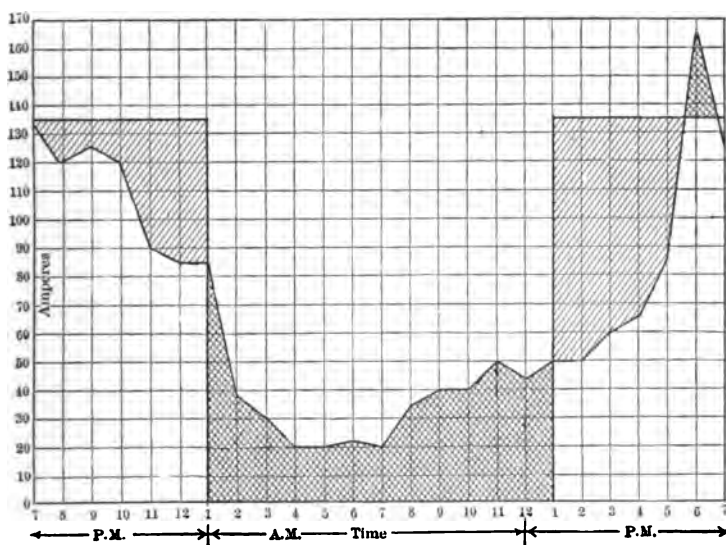


FIG. 177.

never be used on discharge while being charged, the maximum voltage across the lighting bus bars will be  $61 \times 2.1 = 128$

volts.  $\frac{128 - 110}{2} = 9 = \text{number of end cells.}$

Maximum voltage on "boiling" =  $2.6 \times 61 = 158$  volts = maximum voltage required.  $158 - 110 = 48$  = booster voltage due to shunt coil. As previously shown, however, the shunt coil should give about 75 volts or more, if close regulation is desired. Adopting this latter value, the capacity of booster is found to be  $75 \times 210 = 157\frac{1}{2}$ , say 16 K.W. The maximum motor power required will be when passing 210

amperes to the power bus bars, the battery voltage being 2.5 volts per cell. or 152 volts total K.W.,

$$= 152 - 110 \times 210 = 8.85.$$

Allowing 80 per cent. as the efficiency of the booster, the

$$\text{motor H.P.} = \frac{8.85 \times 134}{80} = 15 \text{ H.P.}$$

The cost of equipment would be approximately as follows:

61 cells at \$75.00.....	\$4,575.00
1—300 ampere 10 point end cell switch.....	80.00
Booster and motor.....	950.00
Switchboard and instruments.....	225.00
Installation and connections.....	350.00
Total.....	<u>\$6,080.00</u>

If the equipment were merely for taking up the fluctuations, the capacity of battery would be only about 275 ampere hours, the size of booster would be  $70 \times 100 = 7$  K.W.,

$$\text{and the motor } \frac{70 \times 42 \times 1.34}{80} = 4.9, \text{ say } 5 \text{ H.P.}$$

The cost of this equipment would be about \$2,900 installed.

The losses in the storage system would exceed those of the regulating system by  $18\frac{1}{2}$  K.W. hours' loss in the battery, and 33.6 K.W. hours' losses in booster and motor, making a total of 52 K.W. hours, which are paid for closing down the plant 12 hours, and maintaining 24-hour service. The cost of the fuel and water to produce these 52 K.W. hours should not exceed 2 cents per K.W. hour, or \$1.04 per diem.

Add to this, interest and depreciation at 15 per cent., on the increased cost of the storage equipment =  $6,080 - 2,900 = \$3,180$ . This item is \$1.31 per diem, making a total excess of \$2.35 per day, which is certainly much less than the cost of fuel, water, labor and incidentals for a 24-hour run.

THE END.

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